

Multilayer Collector Optics for Water Window Microscopy

2015 International Workshop on EUV and soft X-Ray Sources

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Dublin, November 11, 2015

Outline

- Introduction
- EUV multilayer optics activities
- Microscopy in the water window
- Summary

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History of optiX fab.

- 1997:** Start of EUV multilayer development @ Fraunhofer IOF
- 2000:** First paper at SPIE “Microlithography” on Mo/Si multilayer mirrors
- 2002:** Start of cooperation with semiconductor industry:
ASML, Cymer, Intel, Jenoptik, Schott Lithotec, Zeiss, etc.
- 2009:** Coating of first NXE:3100 collector mirror
- 2011:** Development of collector refurbishment technologies

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- 1997:** Start of EUV multilayer development @ Fraunhofer IOF
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- 2009:** Coating of first NXE:3100 collector mirror
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-
- 2012:** Foundation of Fraunhofer IOF spin-off company **optiX fab.**
- 2013:** August 1st: Operations start @ **optiX fab.**
- Nov 11, 2015:** Delivery of **3708 EUV and X-ray mirrors** to customers

optiX fab. organization

- **Mission:** Fabrication of customized EUV optics and optical components for EUV lithography @ 13.5 nm, for EUV, soft and hard X-ray applications, synchrotron and FEL beamlines, metrology, R&D, HHG sources, etc.
- **Address:** optiX fab GmbH
Hans-Knöll-Str. 6
D - 07745 Jena
- **URL:** www.optixfab.com

- **Team:**



Torsten Feigl



Marco Perske



Hagen Pauer

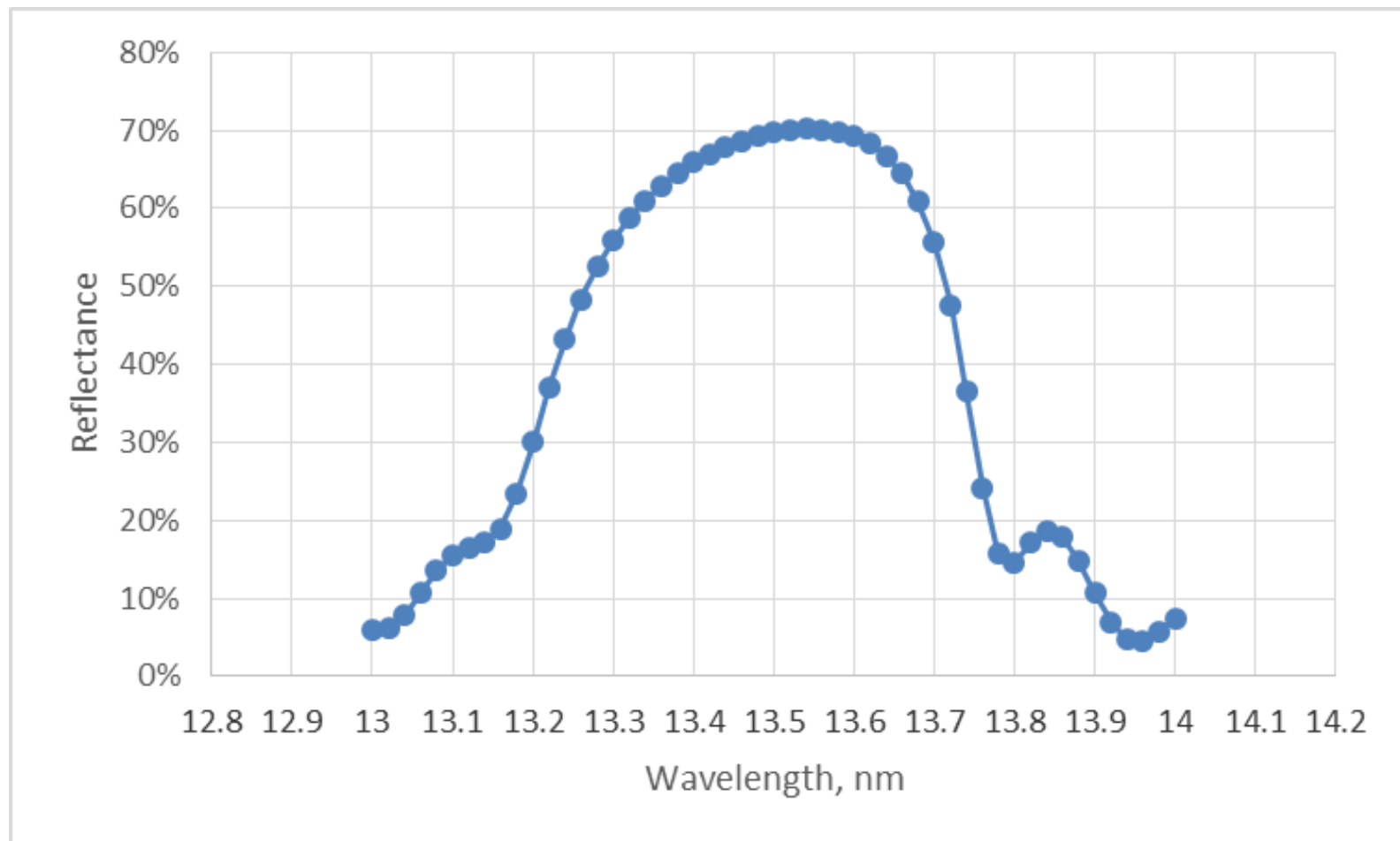


Tobias Fiedler

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Multilayers for 13.5 nm



R = 70.12 %

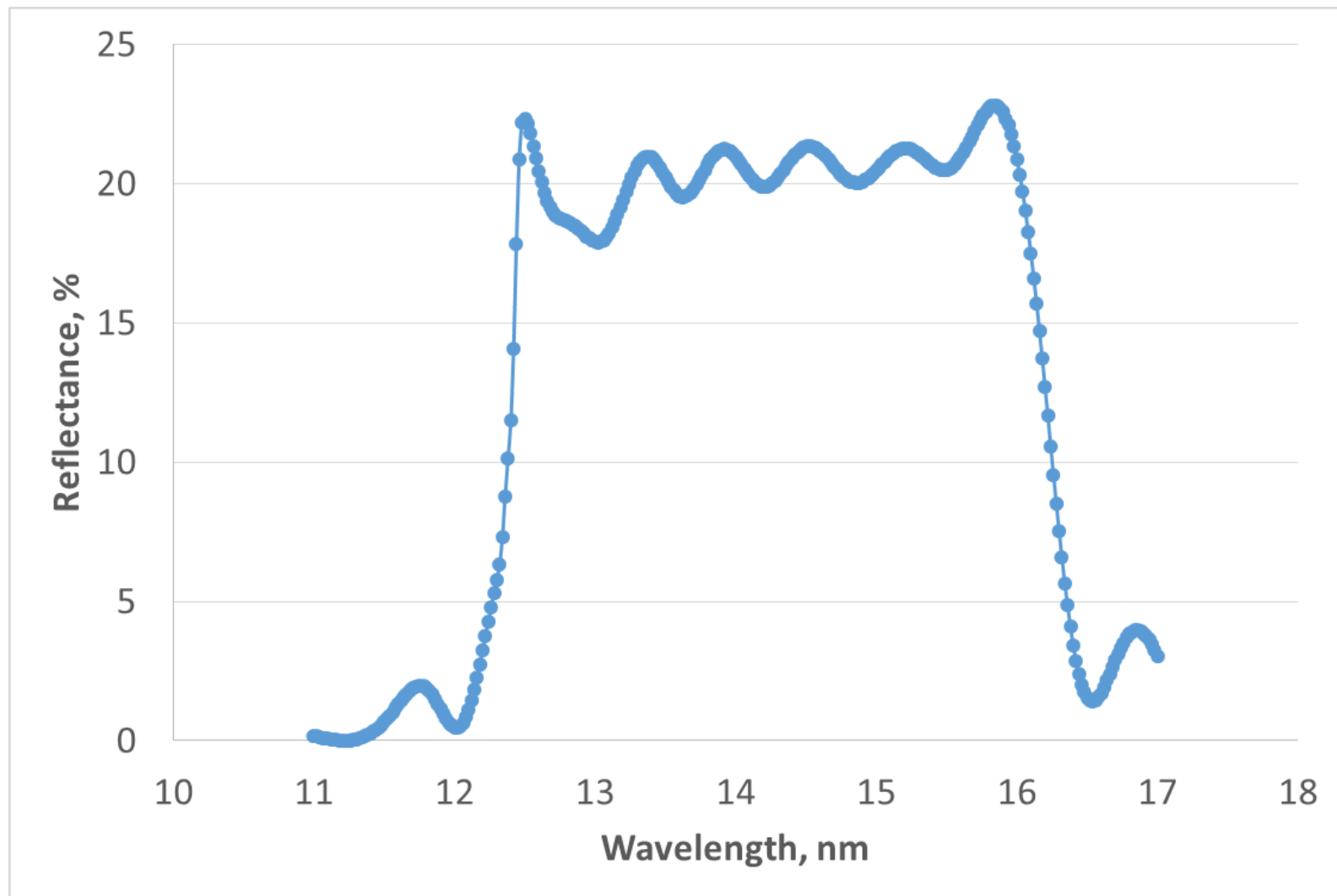
$\lambda = 13.48$ nm

FWHM = 0.528 nm

AOI = 5 deg.

Measured @PTB Berlin

Broadband Multilayers for 12.5 ... 16.0 nm



R ~ 20 %

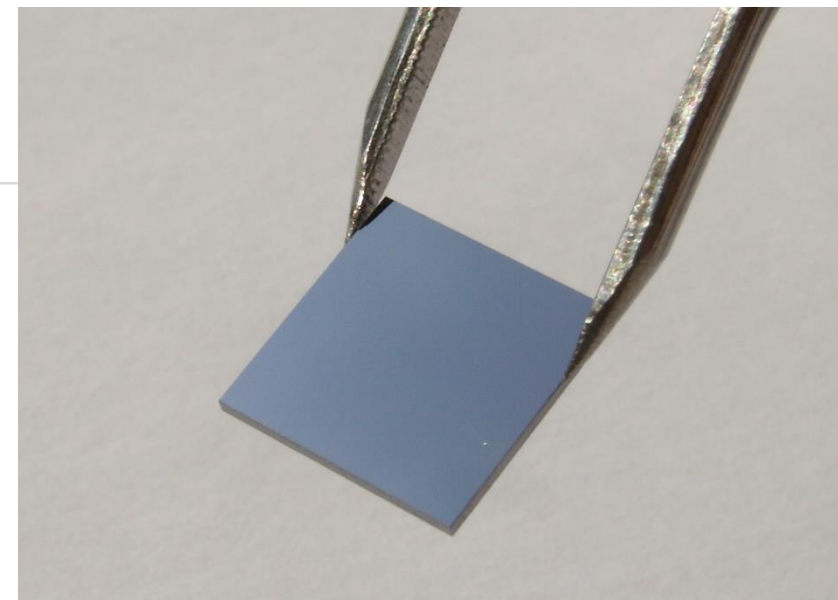
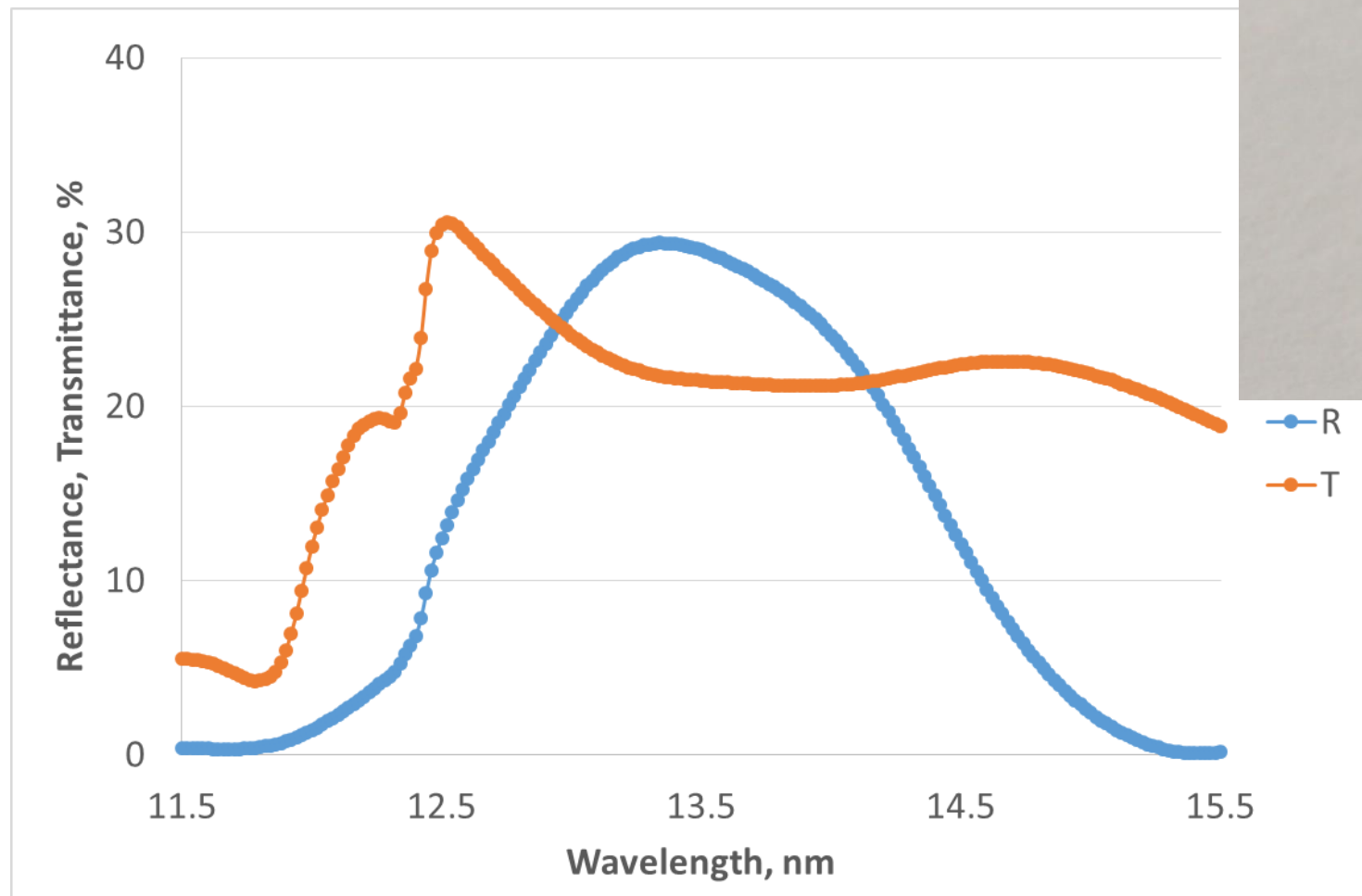
$\lambda = 12.5 \dots 16.0$ nm

FWHM = 3.86 nm

AOI = 30 deg.

Measured @PTB Berlin

Beamsplitters for 13.5 nm



R = 29.0 %

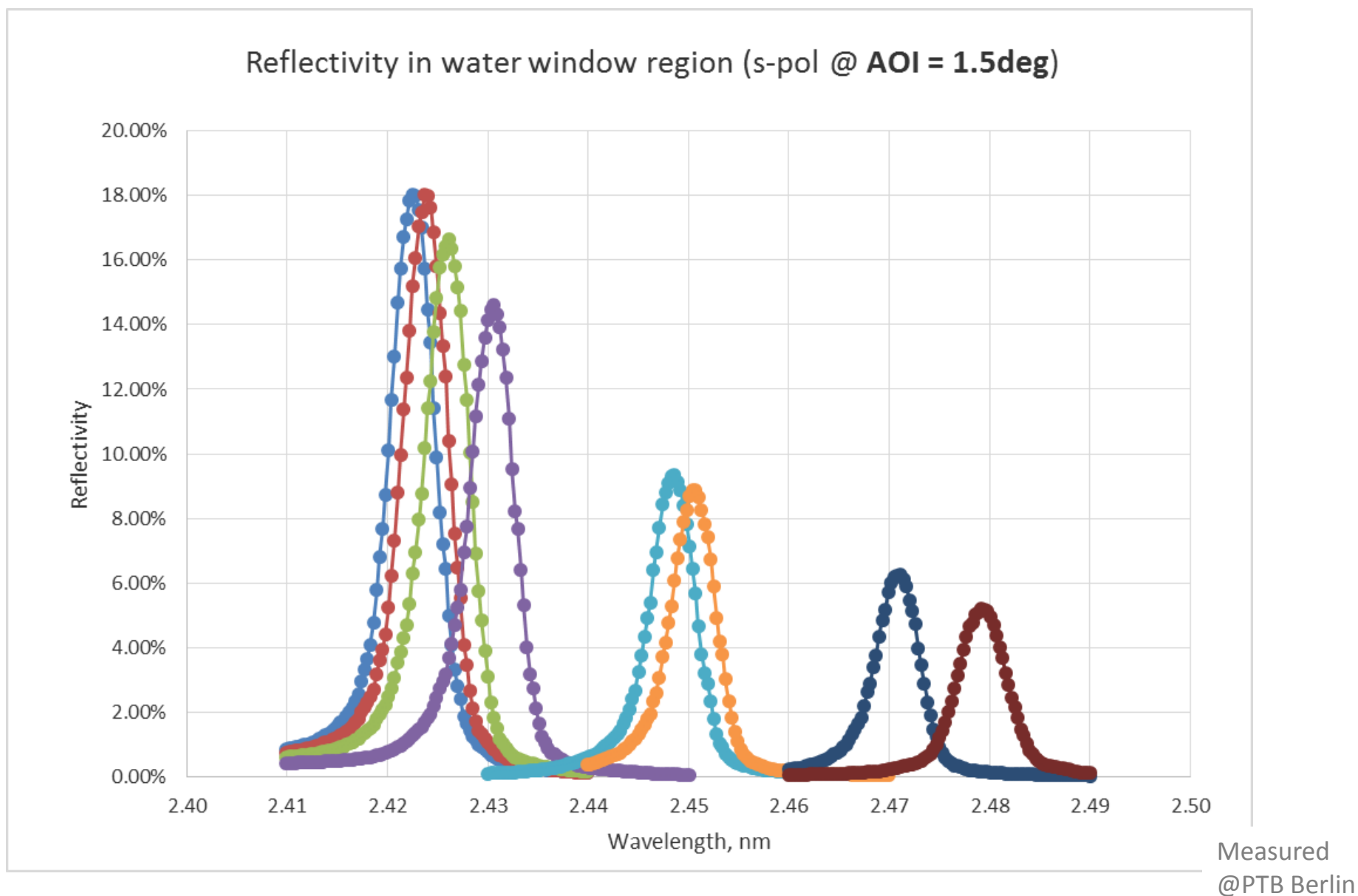
T = 21.5 %

$\lambda = 13.5 \text{ nm}$

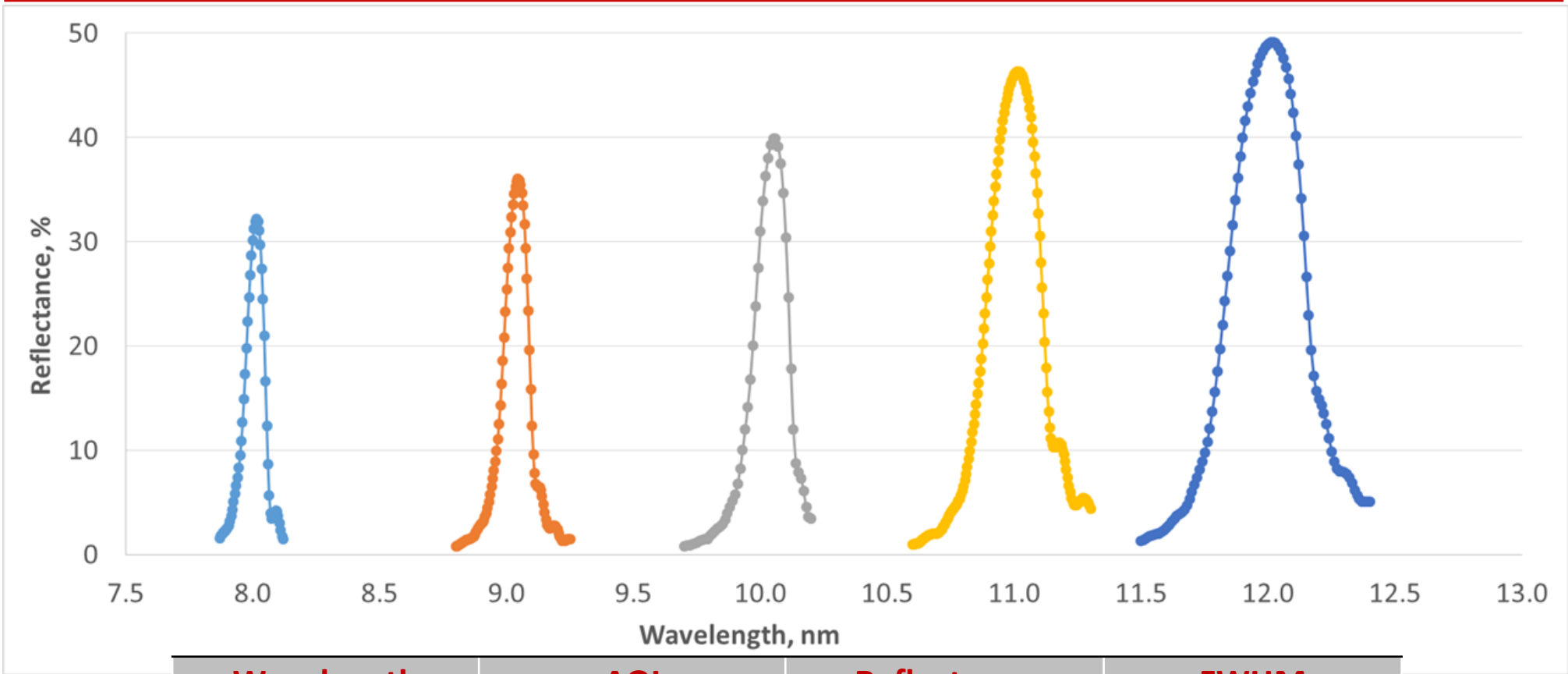
AOI = 45 deg.

Measured @PTB Berlin

Multilayers for the water window



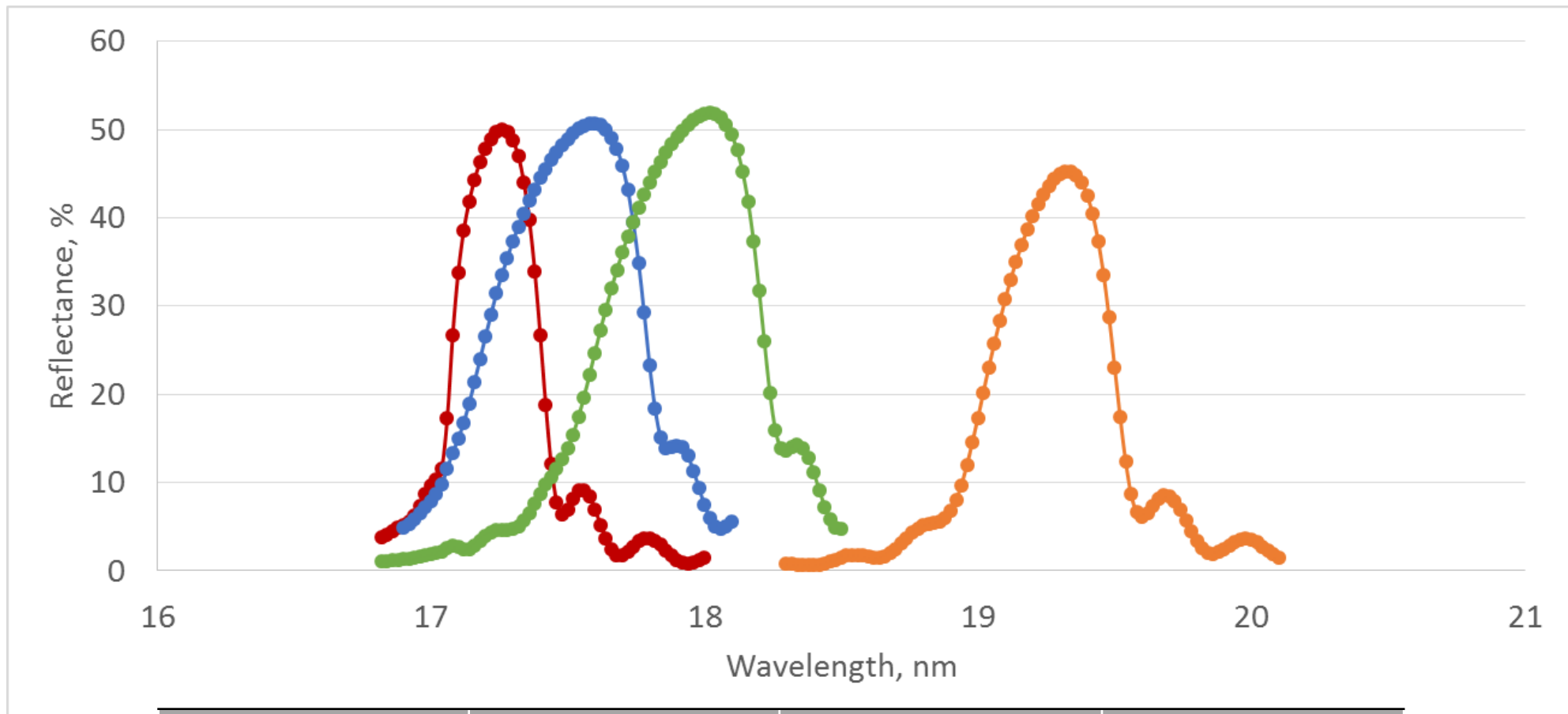
Multilayers for 8 ... 12 nm



Wavelength	AOI	Reflectance	FWHM
8.0 nm	5 deg	32.2 %	0.08 nm
9.0 nm	5 deg	36.0 %	0.11 nm
10.0 nm	5 deg	39.9 %	0.15 nm
11.0 nm	5 deg	46.3 %	0.23 nm
12.0 nm	5 deg	49.1 %	0.33 nm

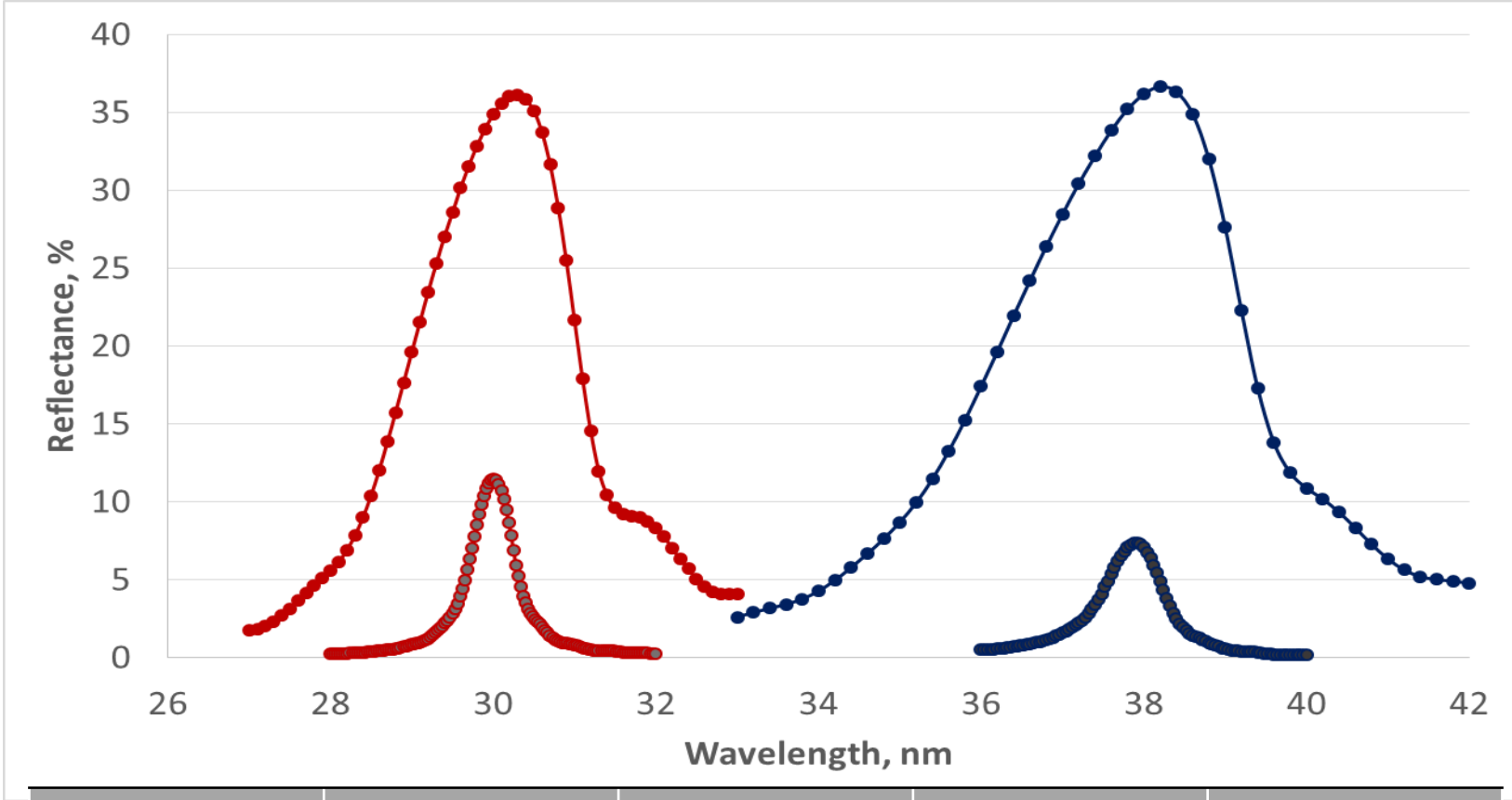
Measured
@PTB Berlin

Multilayers for 17 ... 20 nm



Wavelength	AOI	Reflectance	FWHM
17.24 nm	5 deg	50.0 %	0.33 nm
17.49 nm	5 deg	50.7 %	0.60 nm
17.91 nm	5 deg	51.9 %	0.61 nm
19.27 nm	5 deg	45.3 %	0.47 nm

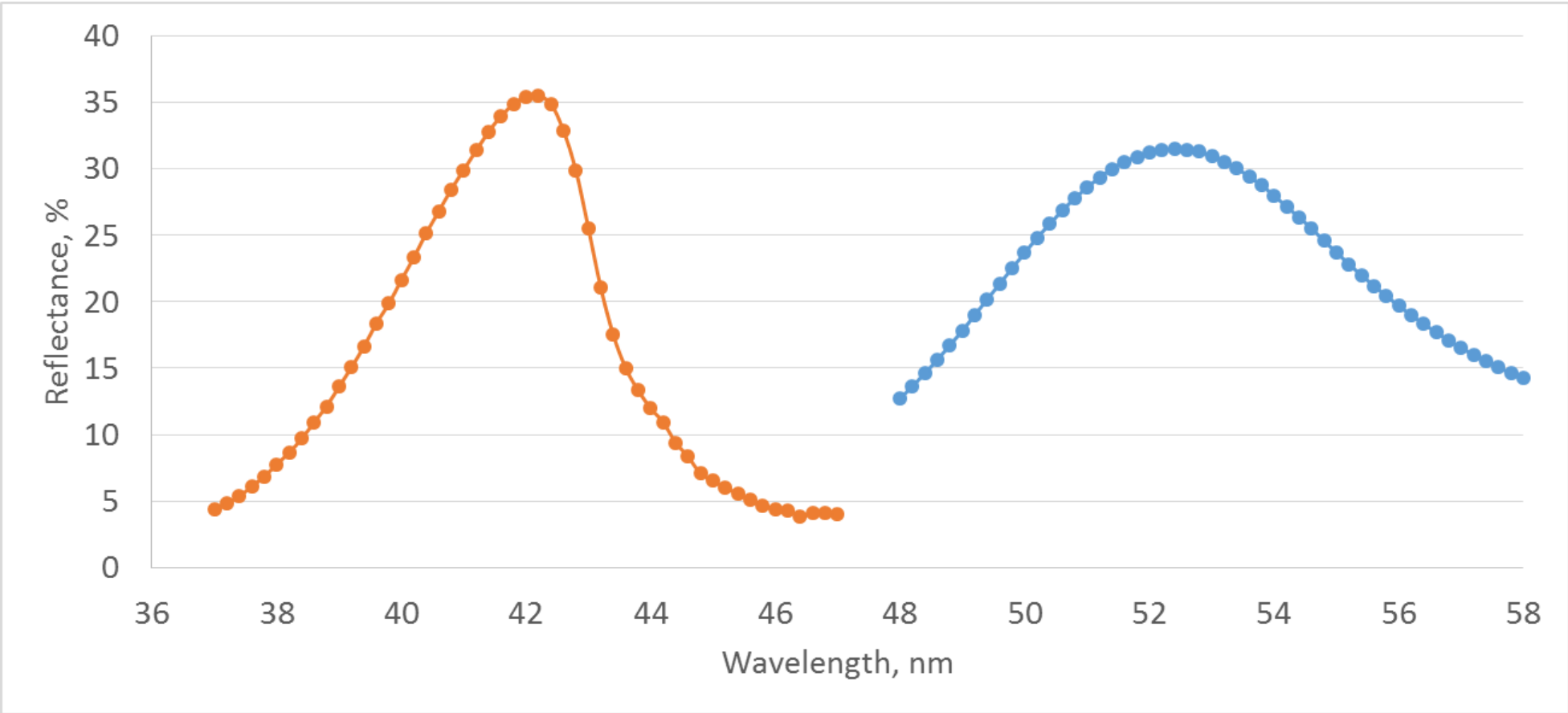
Narrowband Multilayers for 30 ... 38 nm



Wavelength	AOI	Reflectance	FWHM	ML Design
30.0 nm	5 deg	36.1 %	2.17 nm	
30.0 nm	15 deg	11.5 %	0.60 nm	narrow band
37.9 nm	15 deg	36.7 %	3.28 nm	
38.0 nm	15 deg	7.4 %	0.86 nm	narrow band

Measured
@PTB Berlin

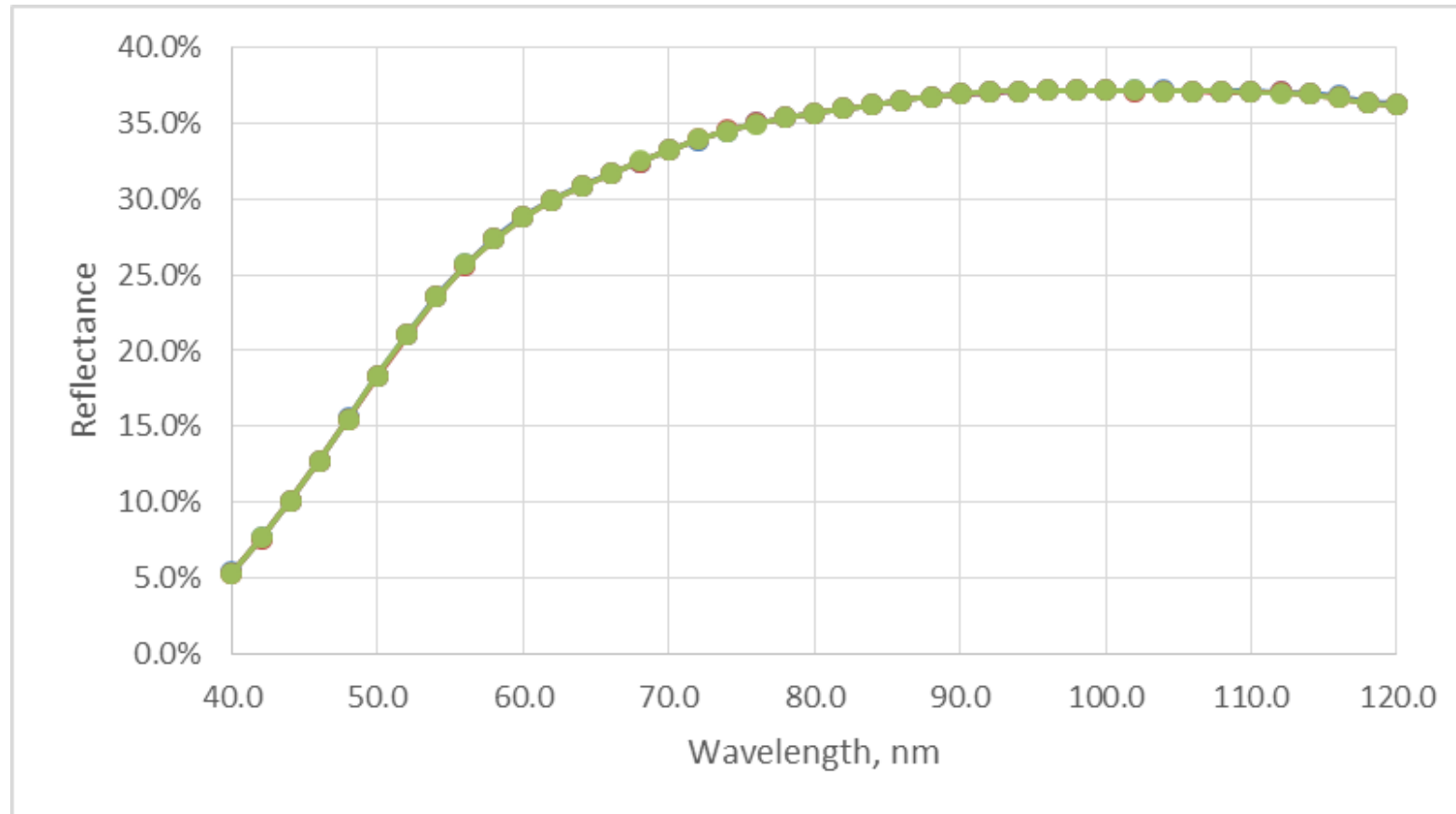
Multilayers for 42 ... 52 nm



Wavelength	AOI	Reflectance	FWHM
41.5 nm	1.5 deg	35.6 %	3.86 nm
52.4 nm	1.5 deg	31.5 %	4.25 nm

Measured
@PTB Berlin

Mirrors for 40 ... 120 nm



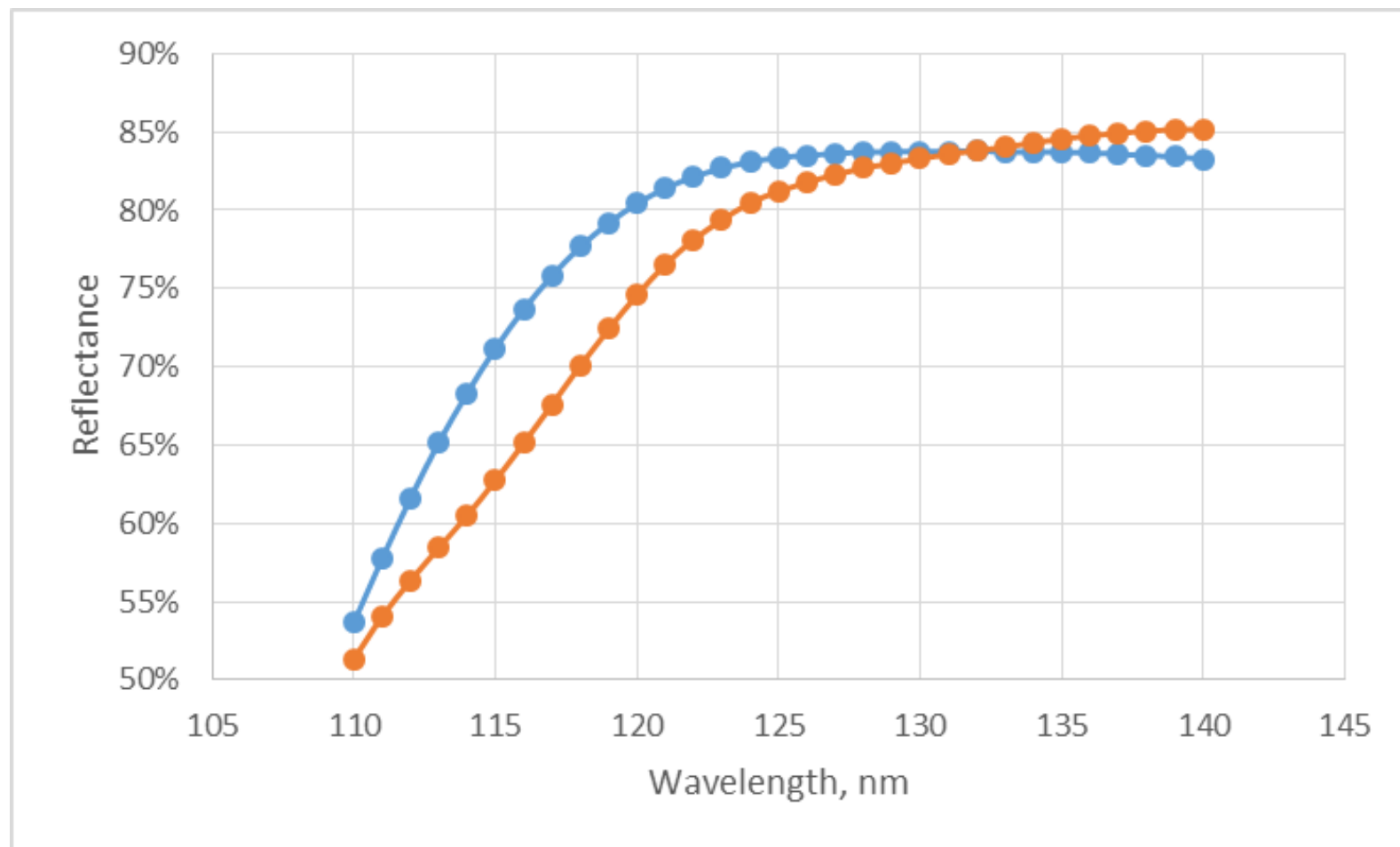
$R > 30.0 \%$

$\lambda = 60 \dots 120 \text{ nm}$

AOI = 1.76 deg.

Measured @PTB Berlin

Mirrors for 110 ... 140 nm



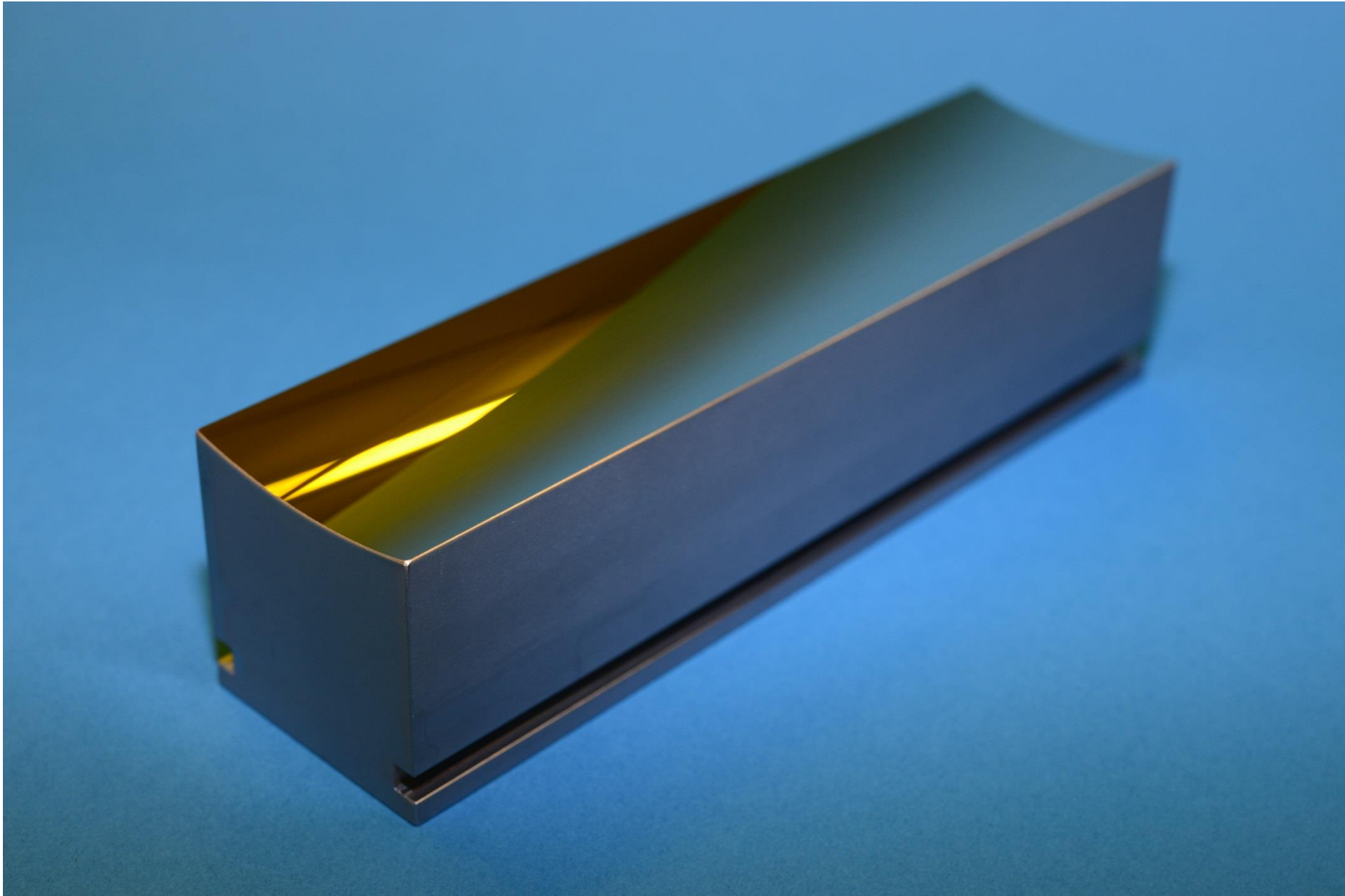
$R > 80.0 \%$

$\lambda = 120 \dots 140 \text{ nm}$

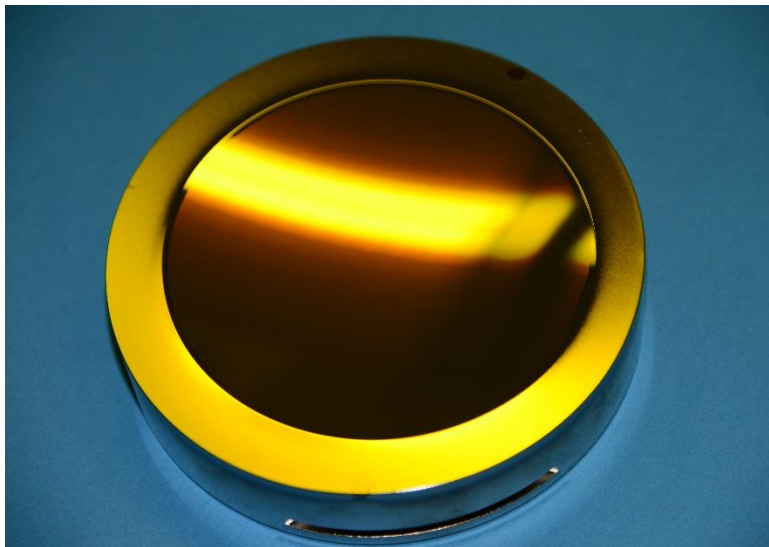
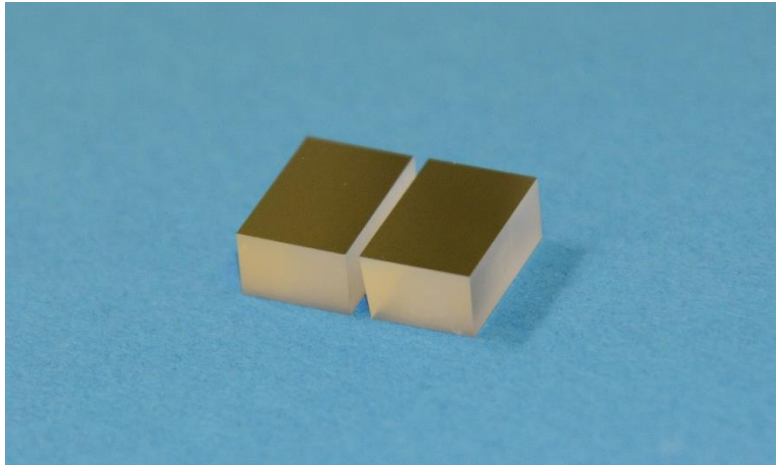
AOI = 1.76 deg.

Measured @PTB Berlin

Gold coated synchrotron optics



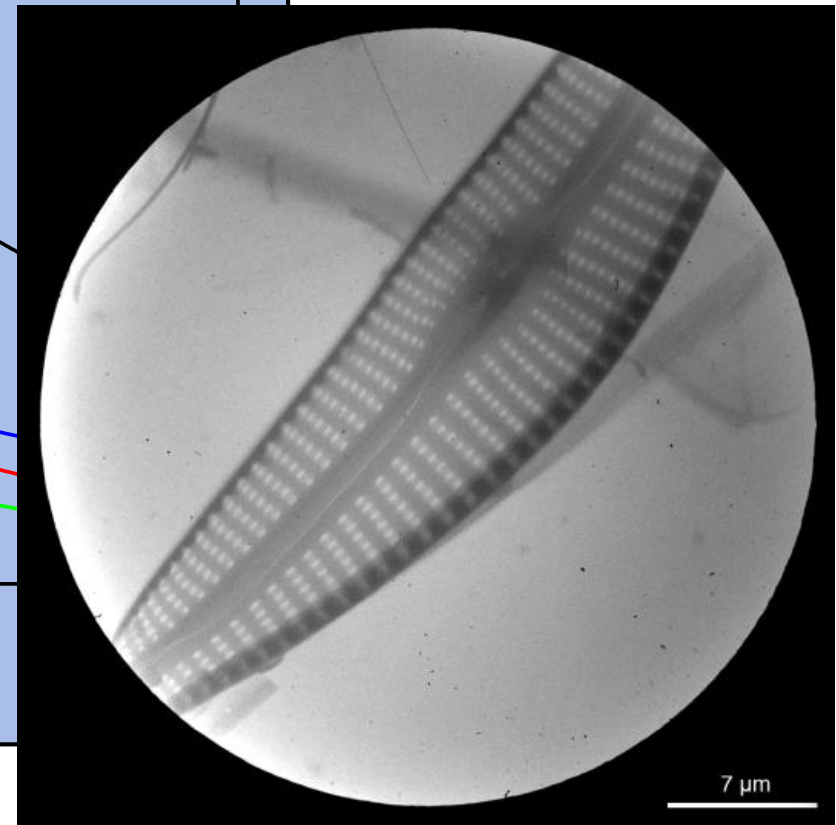
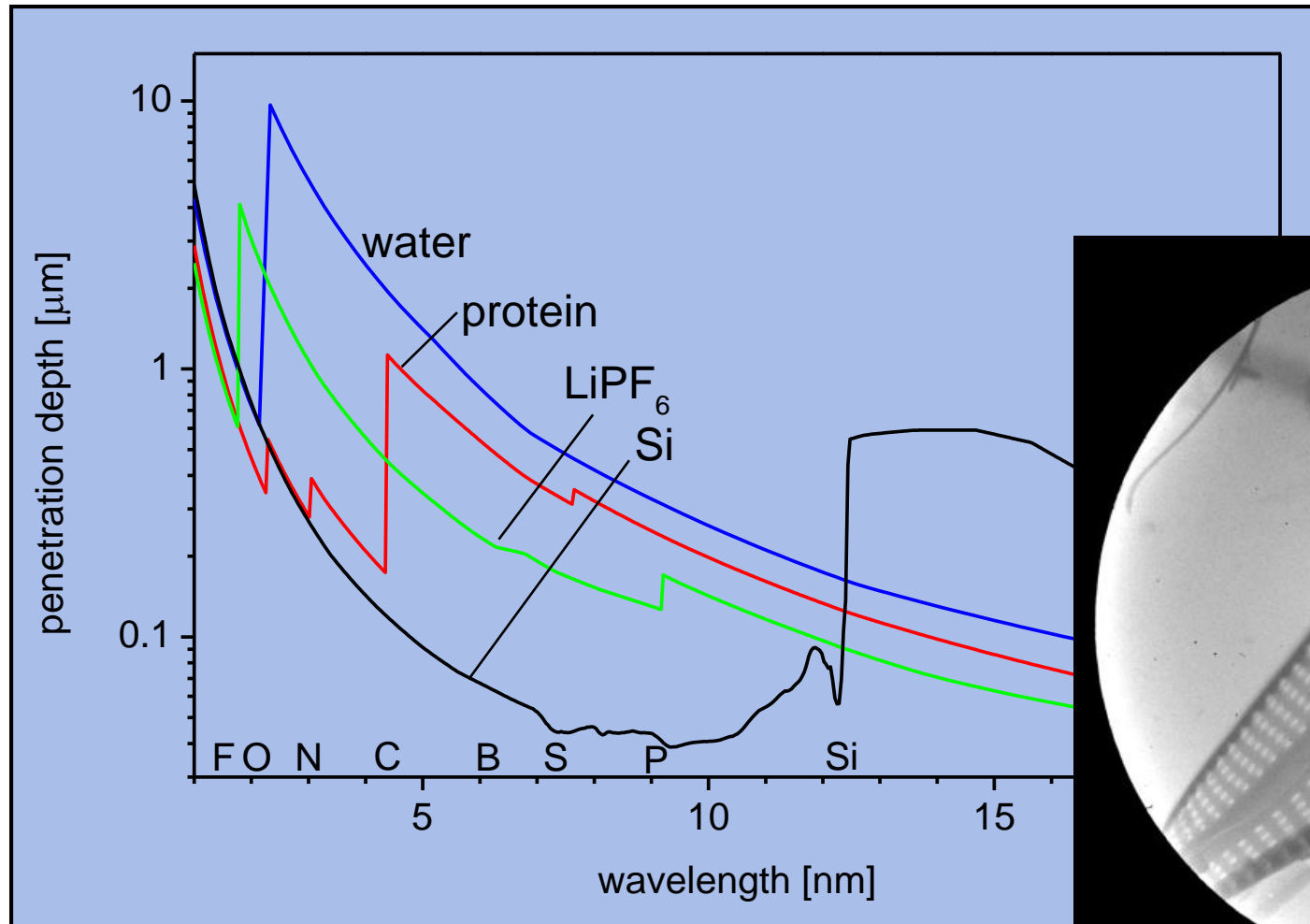
EUV optics – made by optiX fab



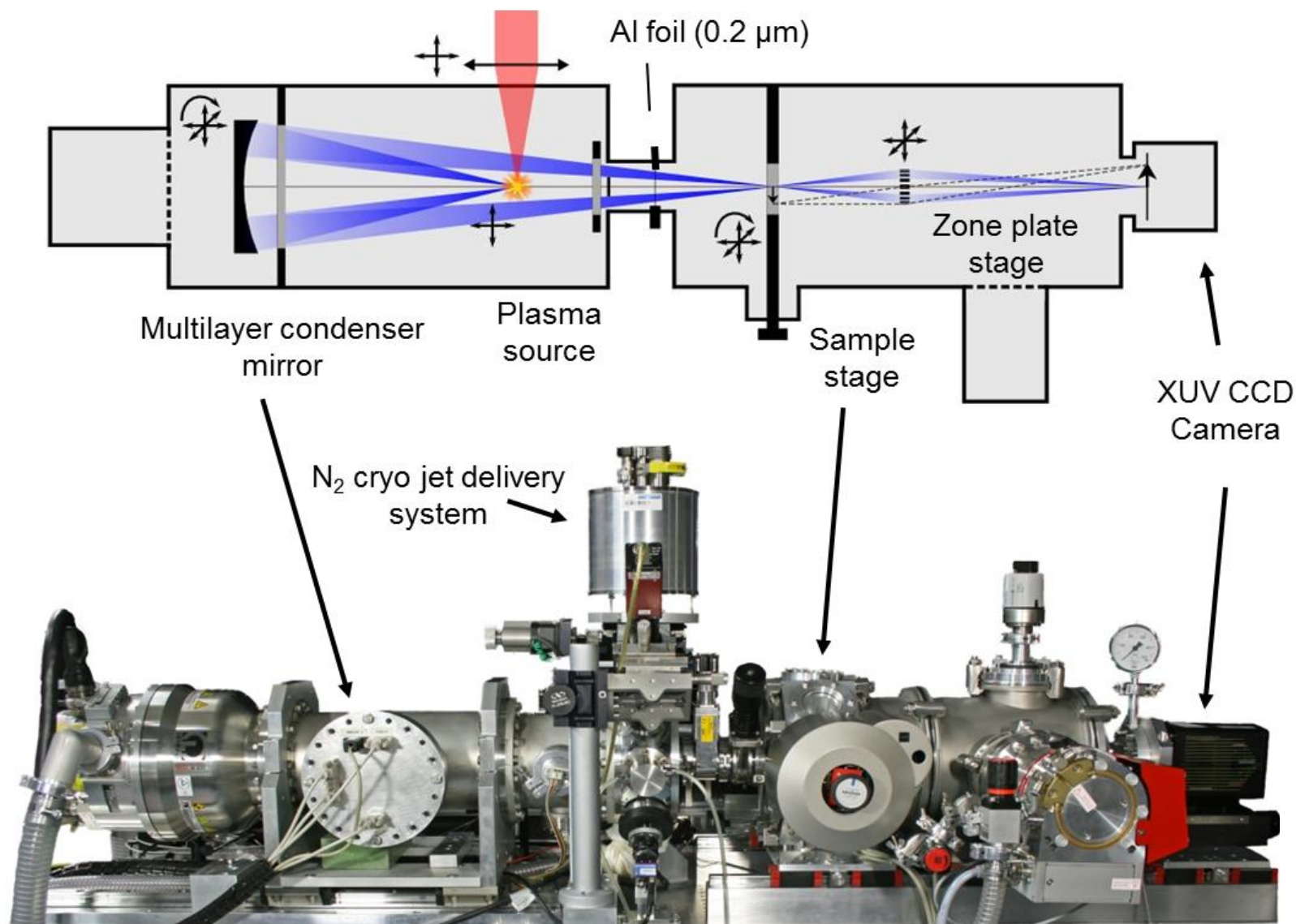
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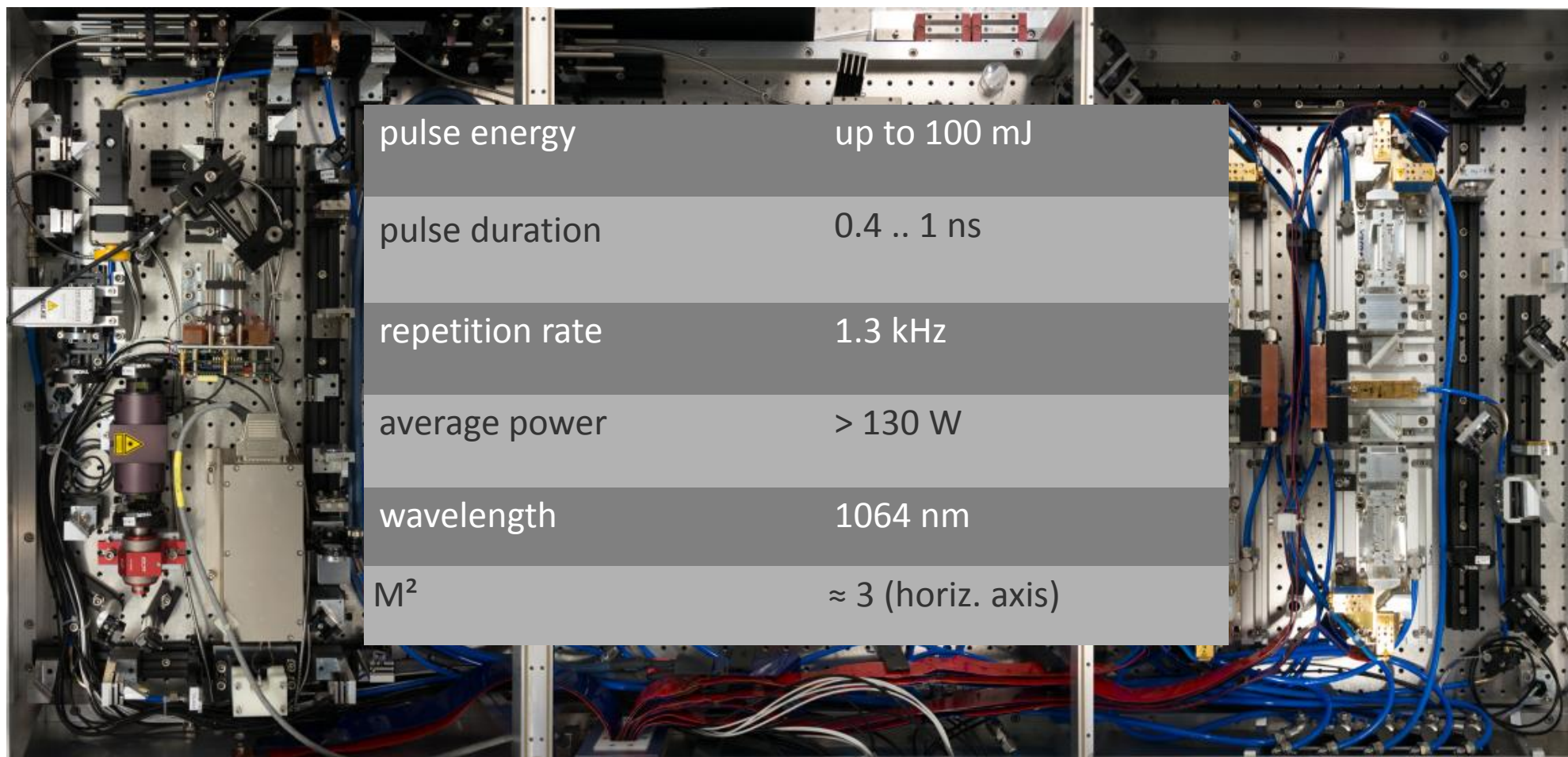
Water window microscopy



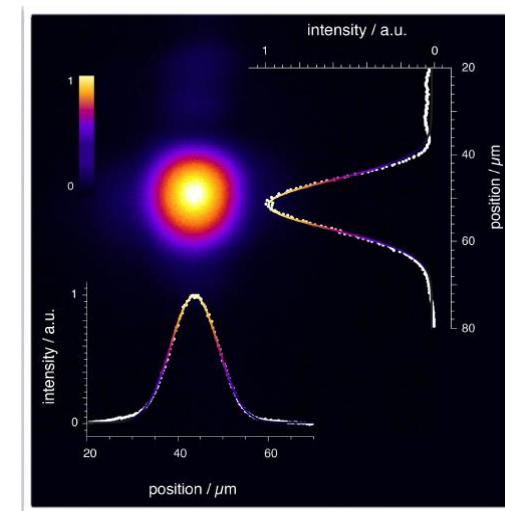
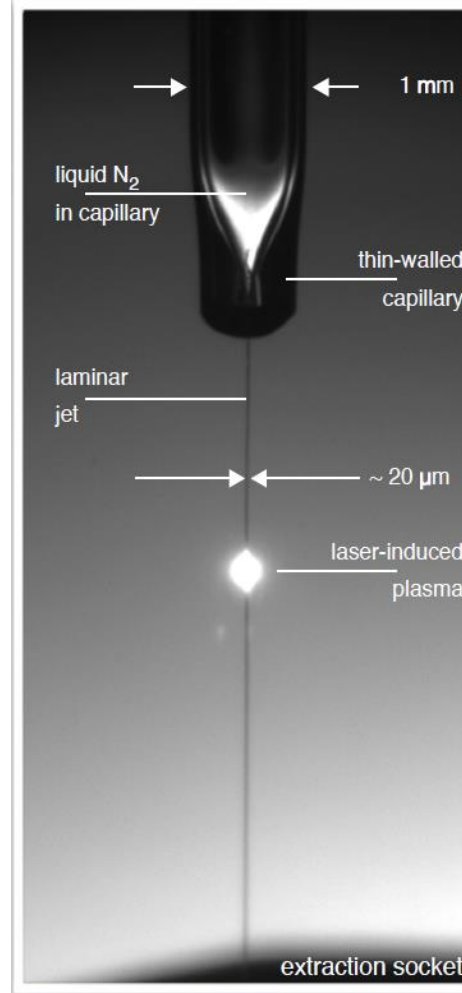
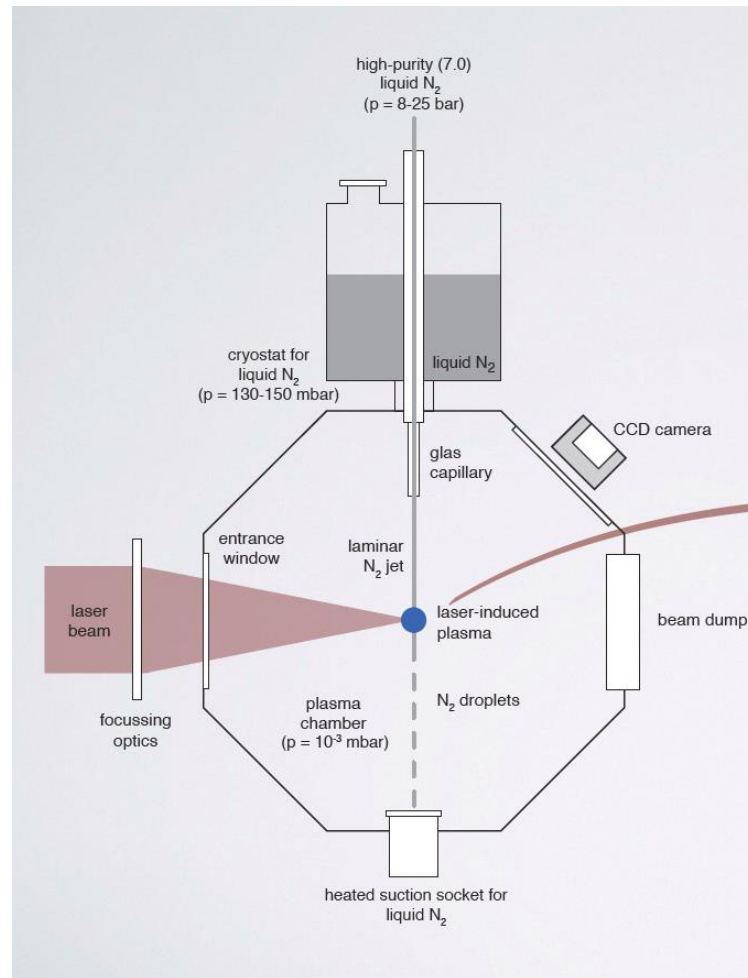
Laboratory Transmission X-ray Microscope (LTXM)



Slab laser system



Liquid nitrogen jet target system

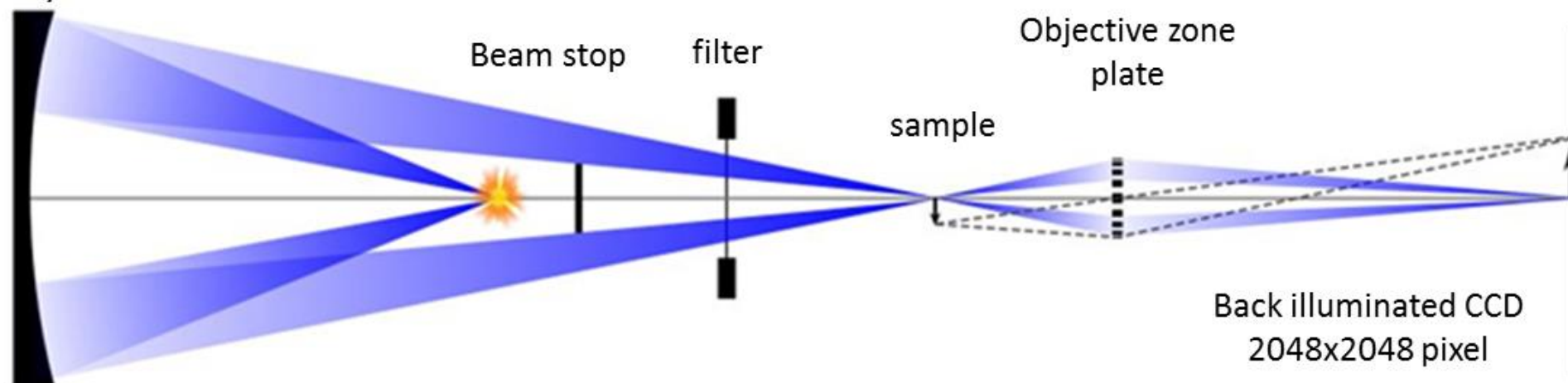


Laser beam focus

Horizontal: $10.5 \pm 0.5 \mu\text{m}$
Vertical: $11.4 \pm 0.5 \mu\text{m}$

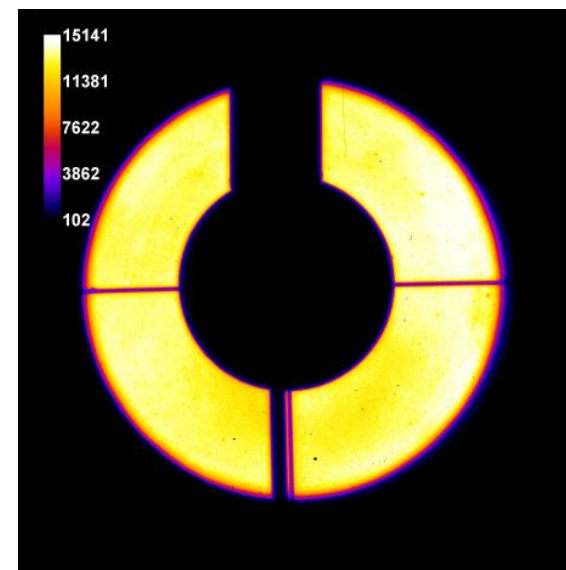
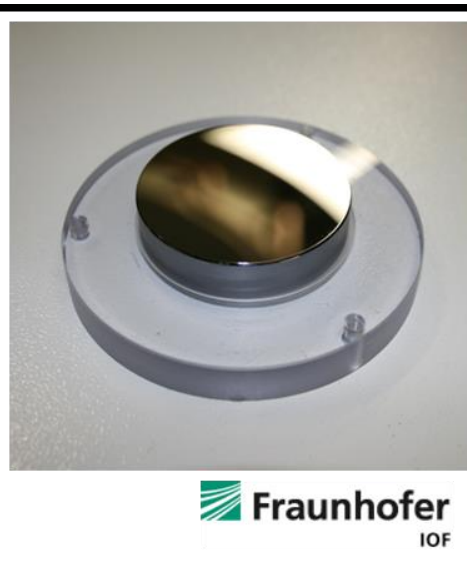
Laboratory Transmission X-ray Microscope (LTXM)

Multilayer condenser mirror

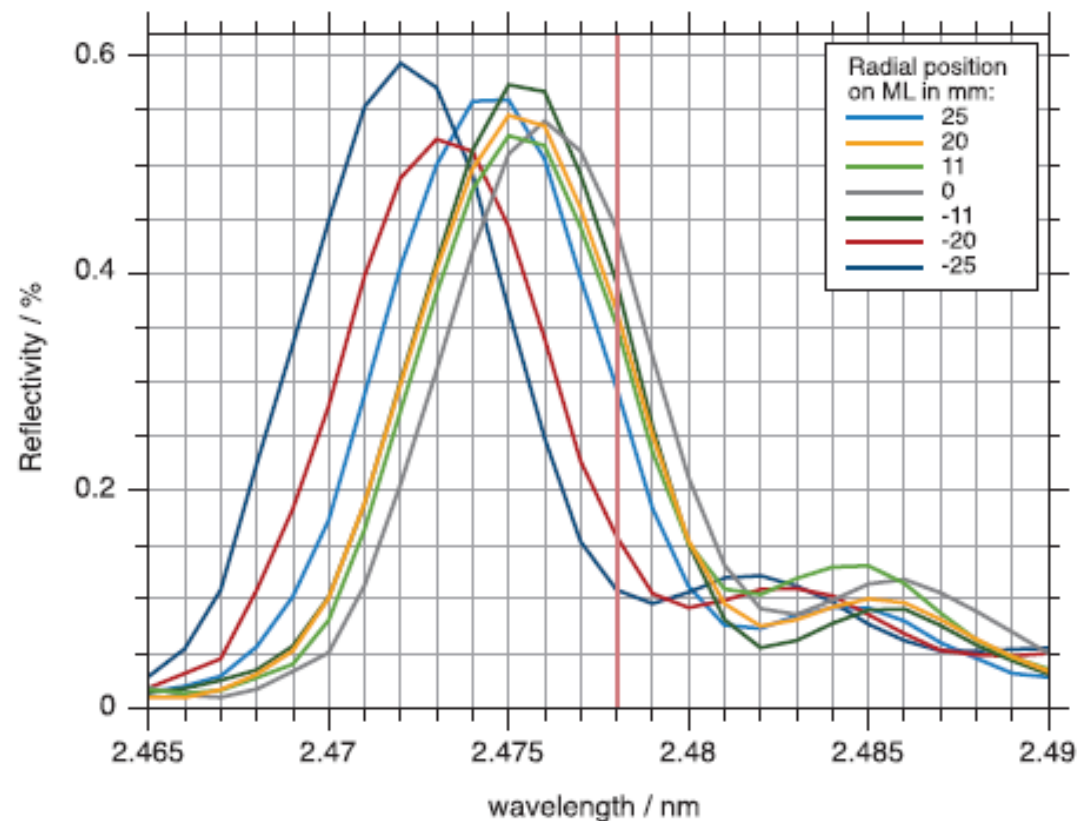
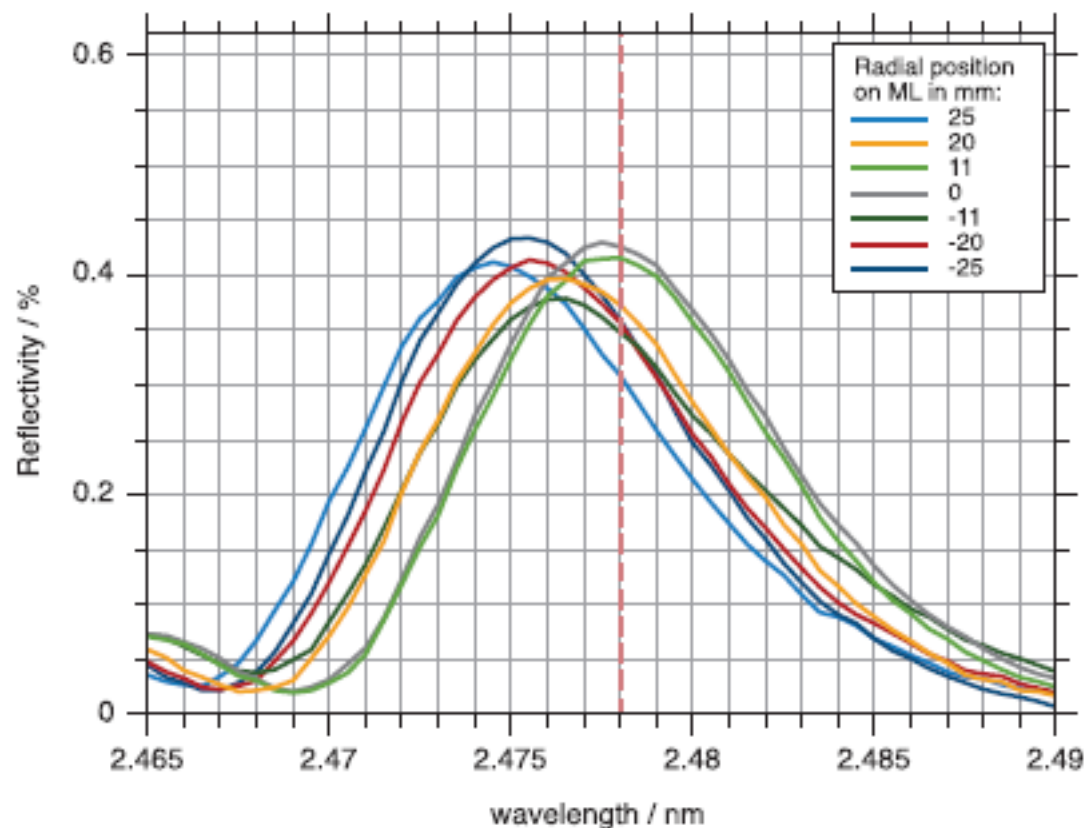


Multilayer condenser

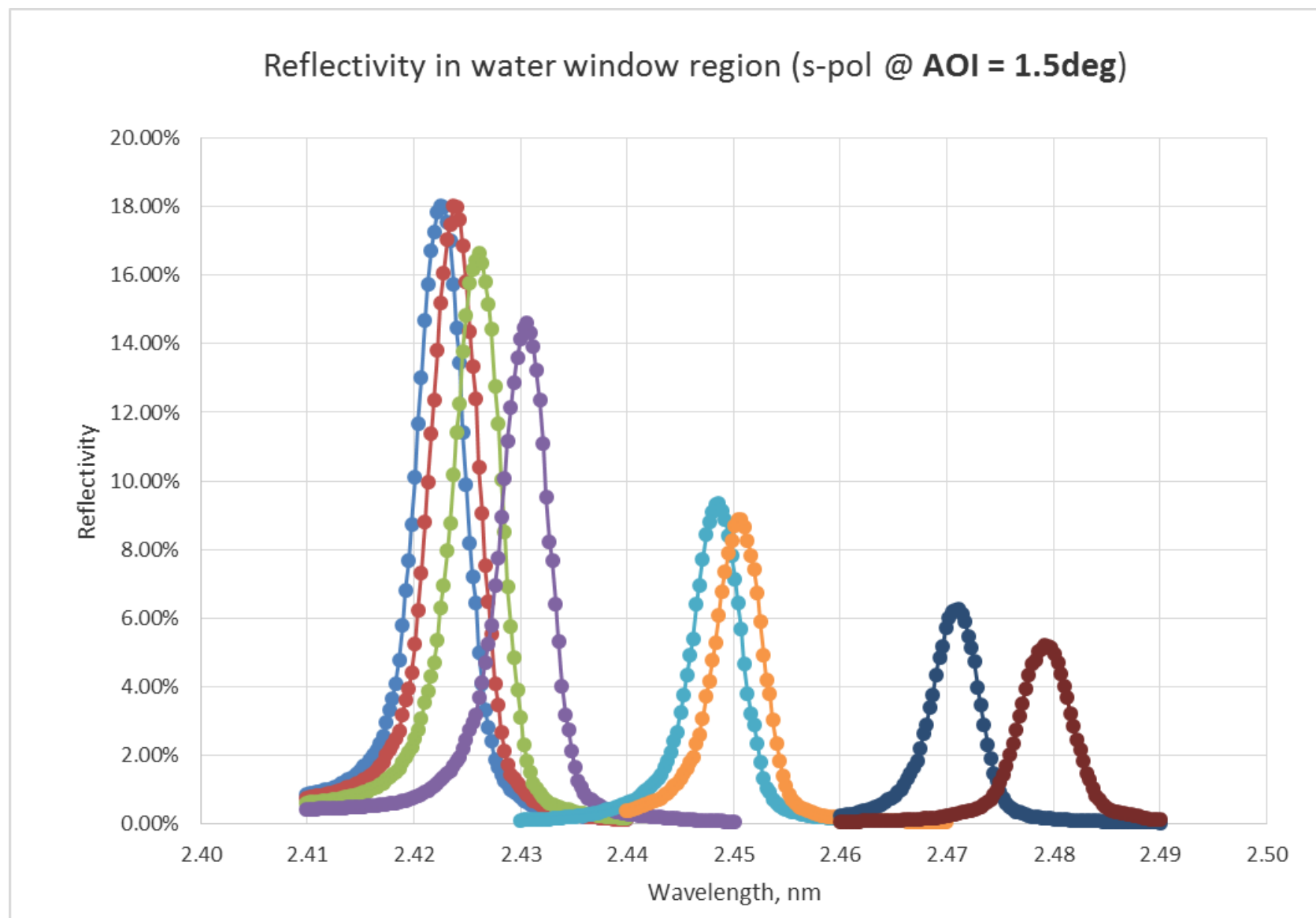
Coating: Cr / V
Wavelength:
(2.478 ± 0.01) nm
Bandwidth: 8 pm
mean reflectivity:
Up to 0.6 %
Radial aperture:
54 mm
Throughput:
> 2*10⁻⁴ sr



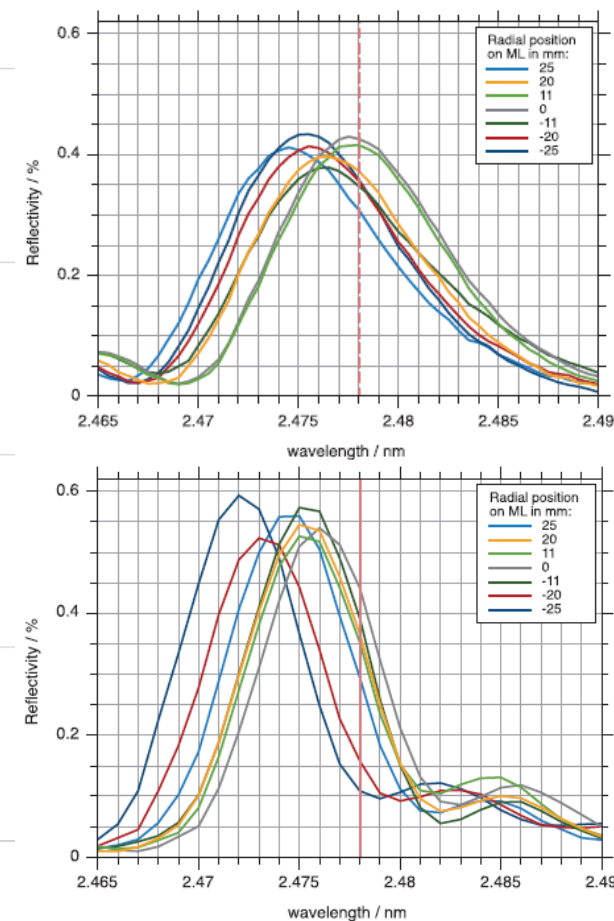
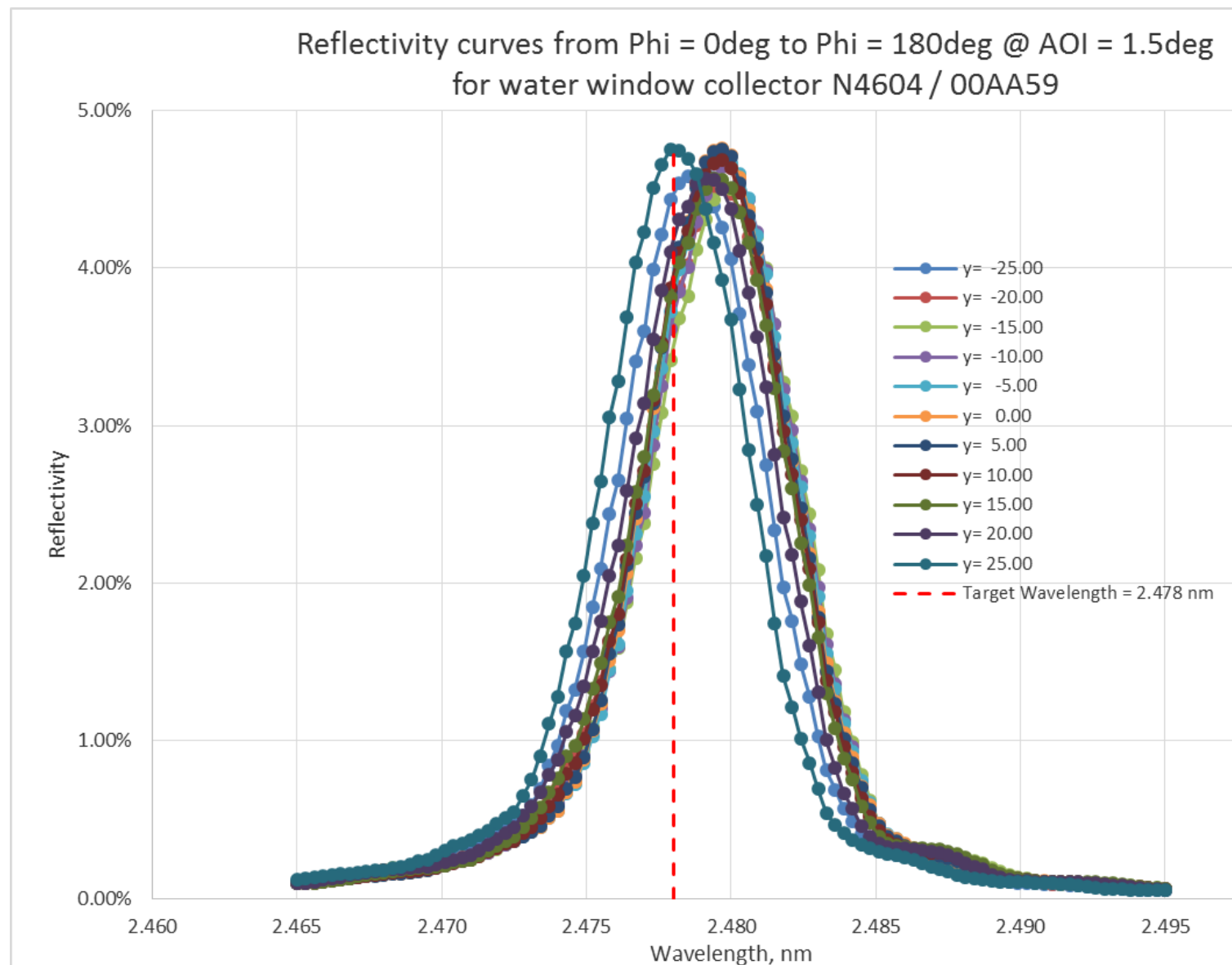
Current water window multilayer collector: optical performance



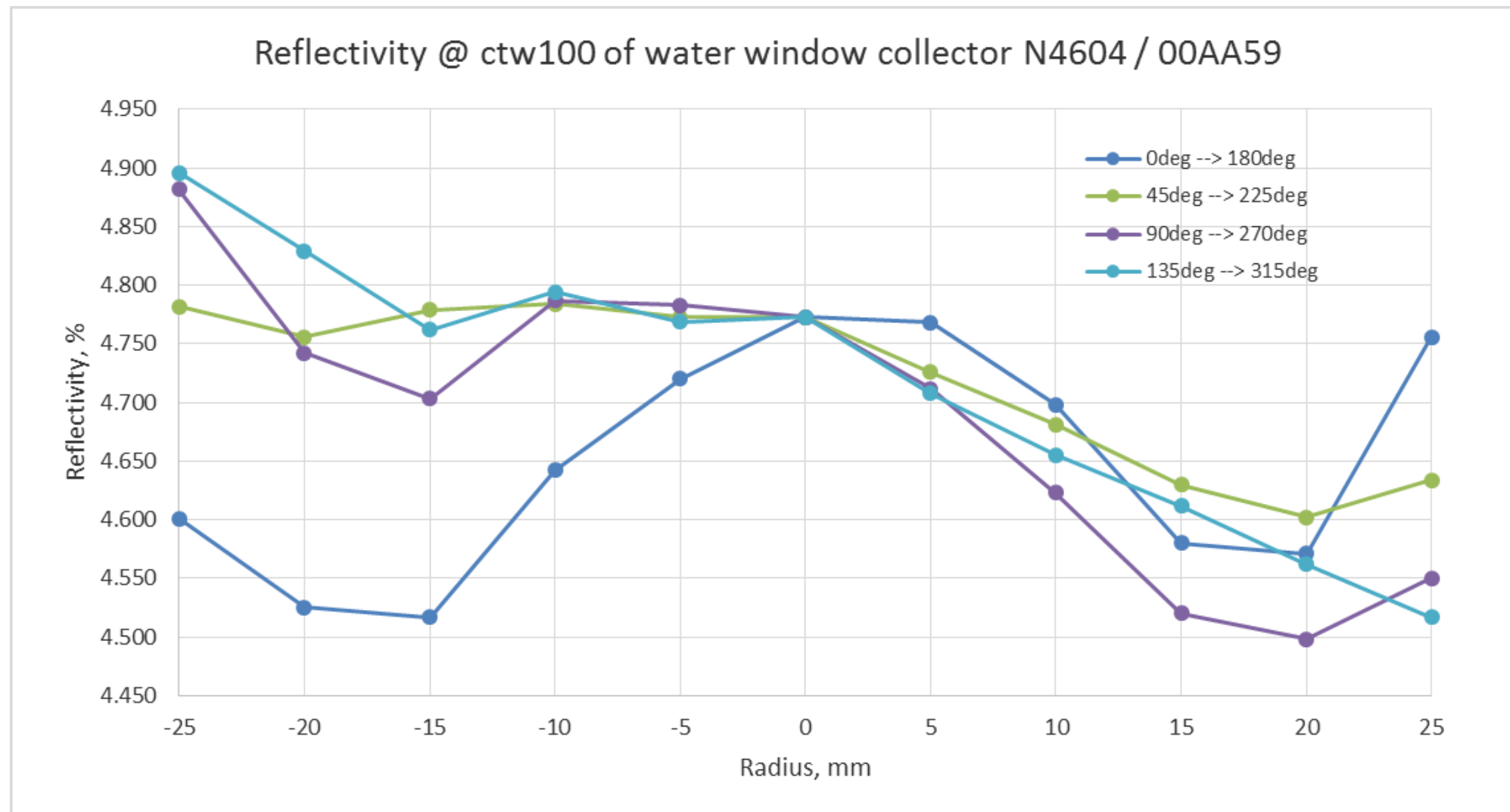
Multilayer development for water window collector



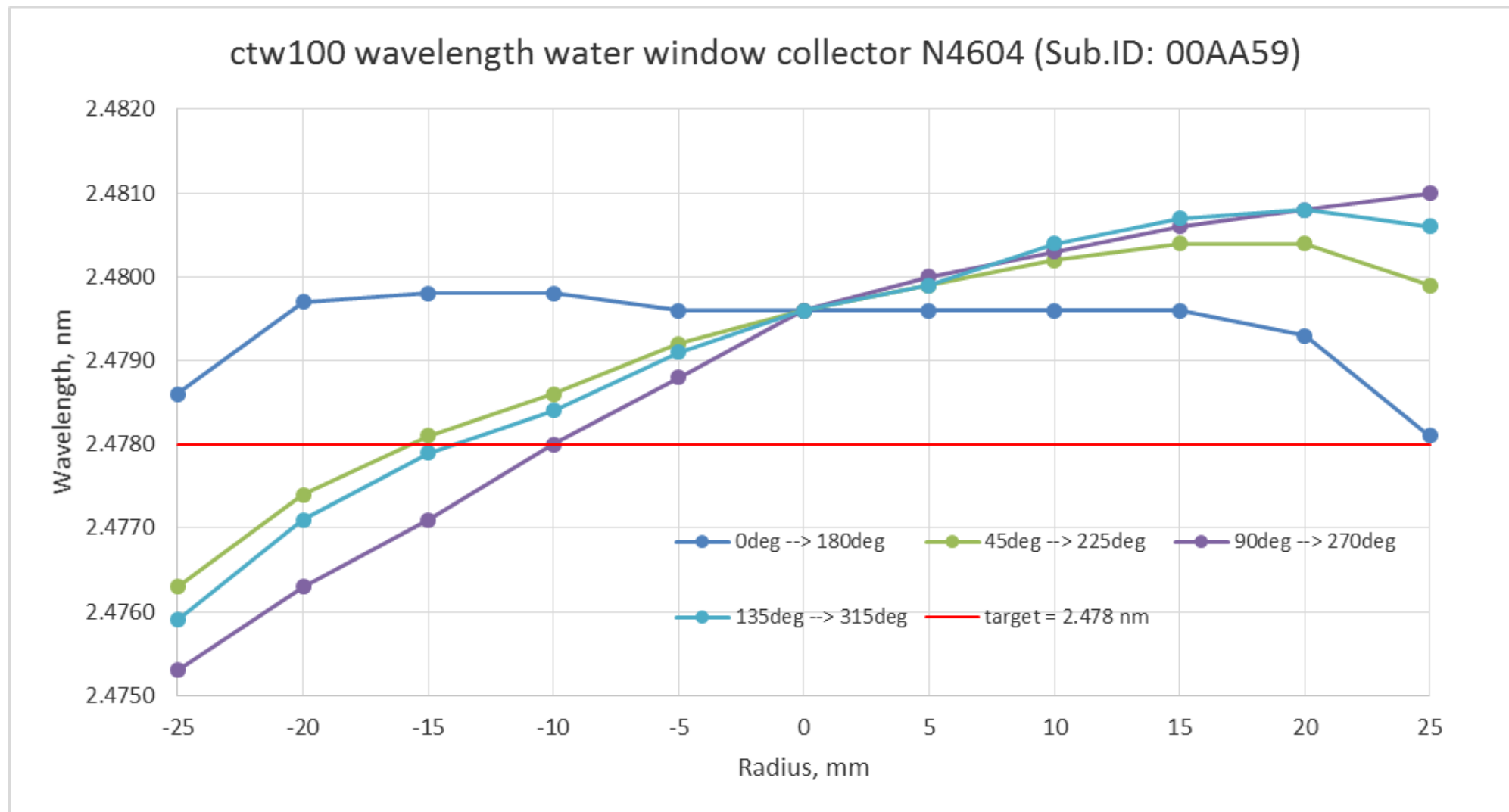
New multilayer collector mirror: EUV reflectance at different radii



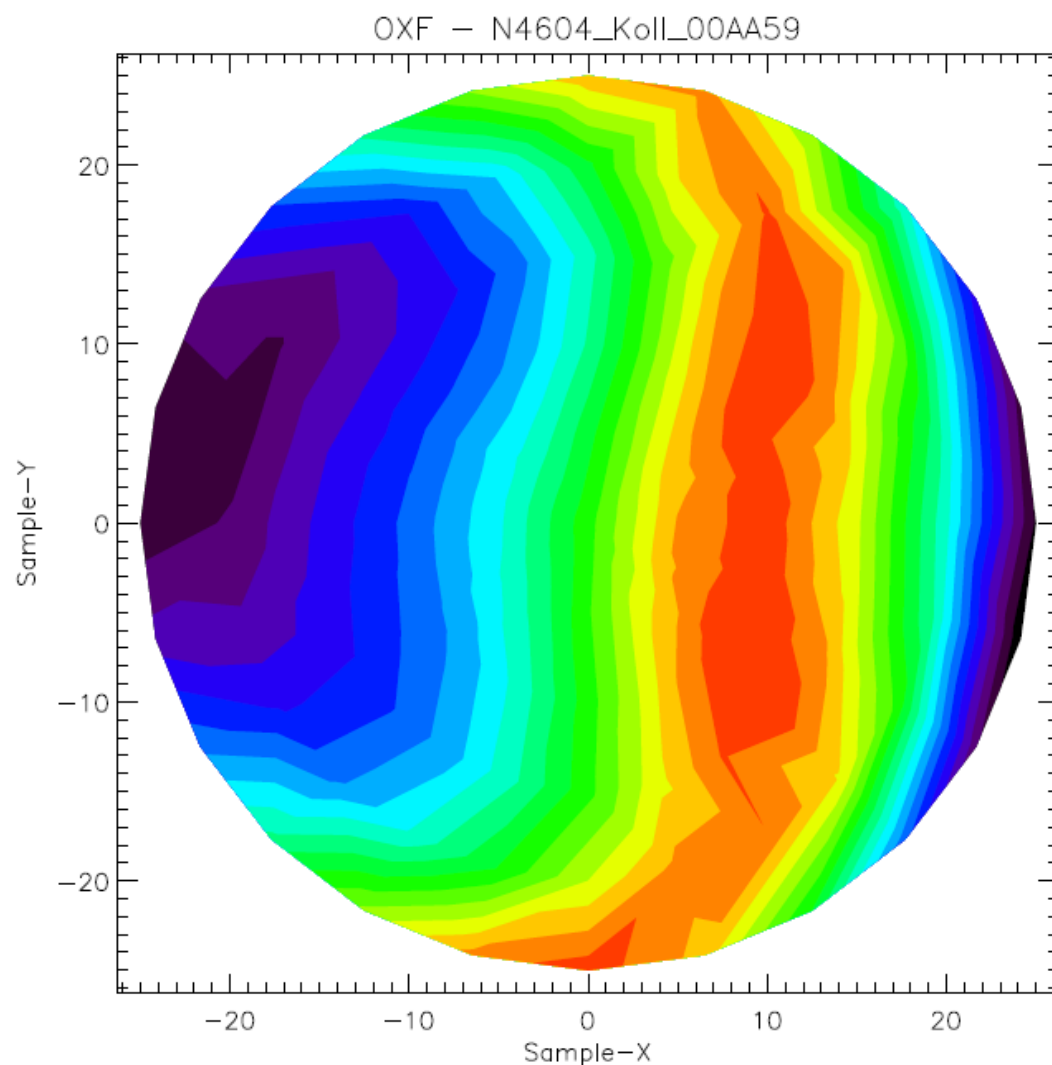
Collector mirror: Peak reflectance at different positions



Collector mirror: Center wavelength at different positions



Collector mirror: Reflectance mapping at $\lambda = 2.478$ nm



#00082 / #00081 / #0
IO_m=0.99991 IO_std=1

AOI=1.500deg

Color change = 0.131%

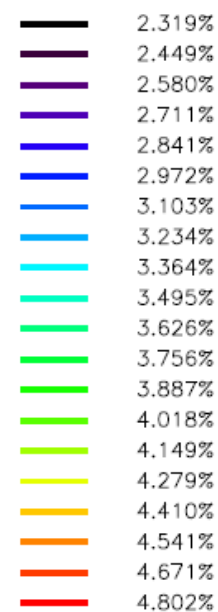
Max(color)=4.802%

Min(color)=2.319%

Max(data)=4.802%

Min(data)=2.319%

$\lambda=2.4780$ nm



R = 3.66 %

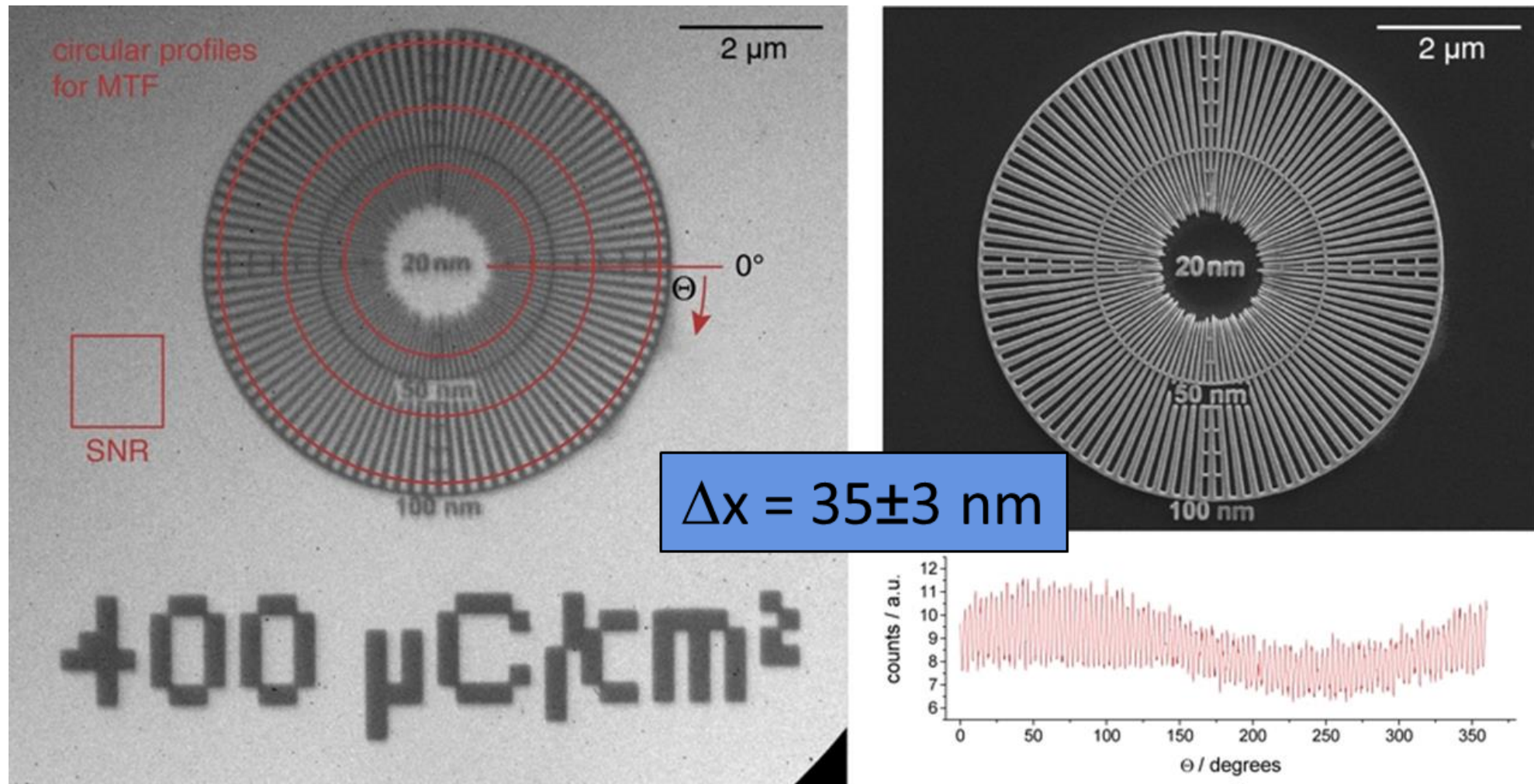
$\lambda = 2.478$ nm

FWHM = 0.005 nm

AOI = 1.5 deg.

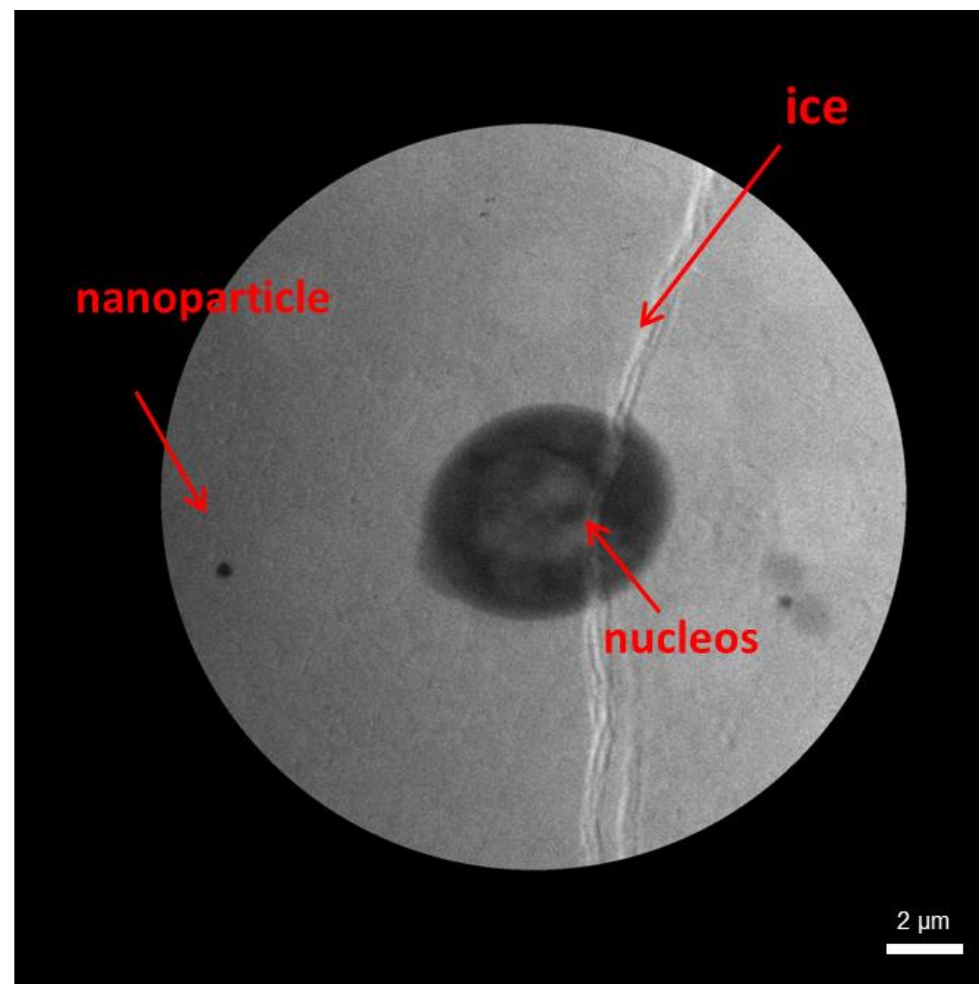
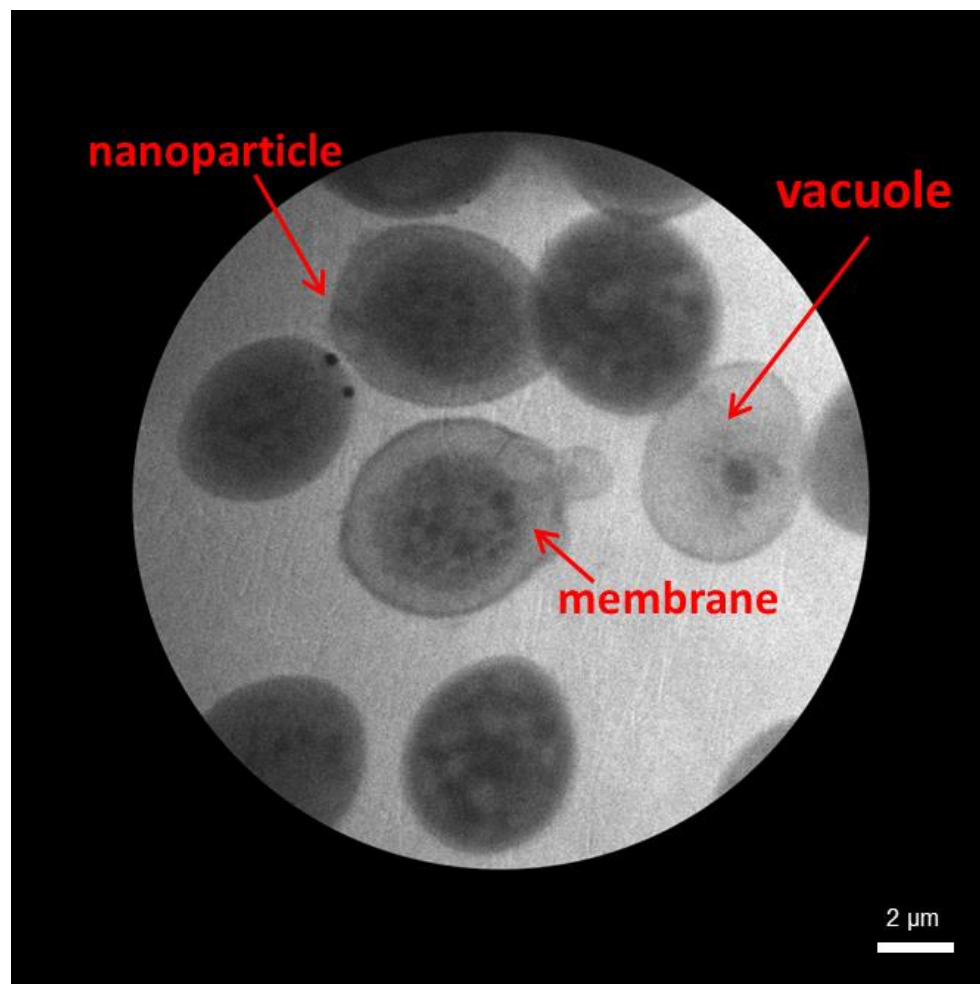
Measured @PTB Berlin

Laboratory Transmission X-ray Microscope: Resolution



C. Seim, H. Legall, H. Stiel et al SPIE (2013) **8678**, 867808

Laboratory Transmission X-ray Microscope: Biological Imaging



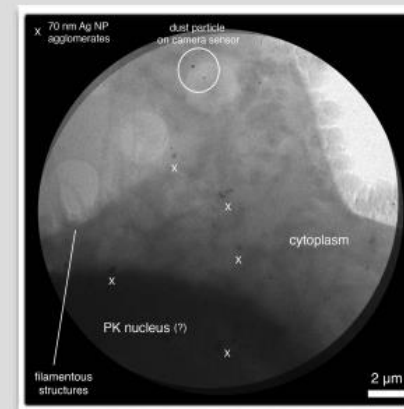
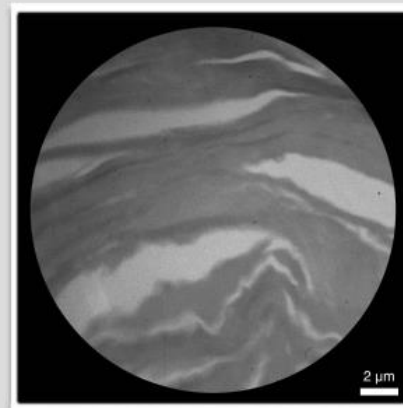
Cryo fixated yeast cells (*Saccharomyces cerevisiae*)
with 250 nm Gold nanoparticles

Laboratory Transmission X-ray Microscope: Biological Imaging

penetration of submicron- and nanoparticles
into human skin



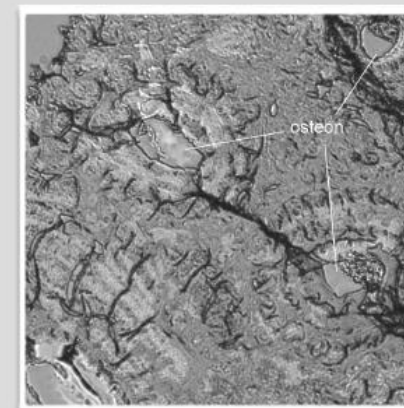
Klinik für Dermatologie, Venerologie und Allergologie



structural analysis of
human bone by means of soft X-ray microscopy



Acoustic Microscopy and Ultrasound Spectroscopy

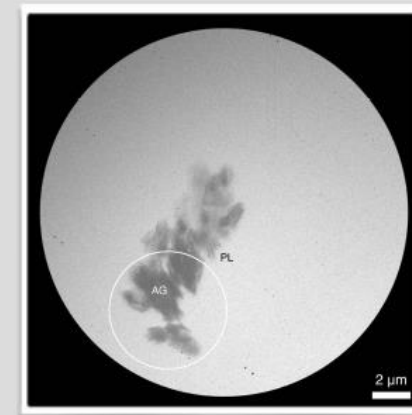


Laboratory Transmission X-ray Microscope: Biological Imaging

X-ray microscopy characterization of ball clay



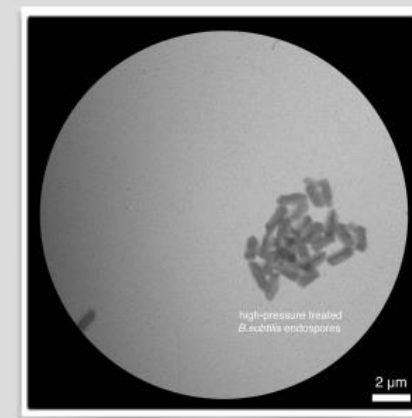
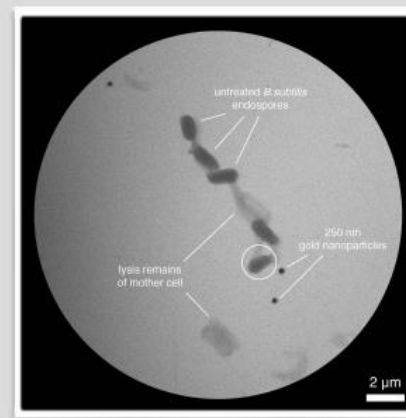
Institute for X-Optics



structural analysis of (high pressure treated) bacterial endospores



Horticultural Engineering



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Summary

- Fabrication of customized EUV and VUV multilayer optics from 2 nm to 200 nm
- Development of new and high-reflective multilayer for 2.478 nm
- Multilayer reflectance: $R = 18.2 \% @ 2.422 \text{ nm}$ (V absorption edge)
- Multilayer reflectance: $R = 5.6 \% @ 2.478 \text{ nm}$ (N_2 emission)
- Collector reflectance: $R = 3.66 \% @ 2.478 \text{ nm}$
- **Factor of 10 improvement!**

Acknowledgements

■ **Fraunhofer IOF:** Thomas Müller, Michael Scheler, Steffen Schulze



■ **PTB Berlin:** Frank Scholze, Christian Laubis and team



■ **Charité Berlin:** Martina Meinke, Kay Raum,



■ **ATB:** Kai Reinecke



■ **HZB:** Gerd Schneider, Stefan Rehbein



■ **Fraunhofer ILT:** Marco Hoeffler, Dominik Esser



■ **AXILON:** Urs Wiesemann, Wolfgang Diete



■ **KTH:** Hans Hertz



Thank you.

optiX fab.

www.optixfab.com